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Article

Selecting Indicators to Assess the Sustainability of Urban Freight Transport Using a Multi-Criteria Analysis

Hana Ayadi [1,*], Mounir Benaissa [2], Nadia Hamani [1] and Lyes Kermad [3]

[1] LTI Laboratory, University of Picardie Jules Verne, 02100 Saint Quentin, France; nadia.hamani@u-picardie.fr
[2] OASIS Laboratory, ISGIS, University of Sfax, Sfax 3029, Tunisia; mounir.benaissa@isgis.usf.tn
[3] QUARTZ Laboratory, University of Paris 8, 93100 Montreuil, France; l.kermad@iut.univ-paris8.fr
* Correspondence: hana.ayadi@u-picardie.fr

Abstract: *Background:* Urban freight transport has recently garnered significant attention from both professionals and academics due to its pivotal role in fostering economic and social development. Despite notable progress, this sector faces challenges that hinder its long-term sustainability. Addressing these issues and ensuring the lasting sustainability of urban freight transport require a thorough assessment and monitoring process utilizing specific indicators. *Methods:* This paper introduces a set of indicators developed using a three-step methodology aimed at assessing the sustainability progress of urban freight transport. Initially, we present a long list of indicators drawn from the existing literature. Subsequently, we consider five essential properties: achievability, data availability, predictability, relevance, and comprehensibility. Lastly, we apply a multi-criteria analysis methodology that utilizes these properties to assess the long lists encountered during the selection process. The chosen indicators are those that do not register a value of "0" for any of the specified properties. To enhance reliability, the indicators are collaboratively identified by a minimum of two experts. *Results:* By carefully selecting 18 indicators based on five sustainability dimensions (economic, environmental, social/societal, political, and spatial), our approach ensures a robust evaluation framework. *Conclusions*: These indicators serve as valuable tools for stakeholders in comprehensively evaluating the sustainability aspects of urban freight transport.

Keywords: assessment; indicator systems; sustainability dimensions; sustainability indicators; sustainability; urban freight transport; multi-criteria analysis; selecting approach

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1. Introduction

Nowadays, improving the sustainability of urban freight transport (UFT) is paramount due to the significant increase in goods deliveries in city centers and the rise in the number of heavy goods vehicles, leading to congestion problems [1]. To address this issue, freight transport actors are becoming increasingly aware of the importance of assessing the current situation and proposing future measures to promote UFT sustainability. In this context, specific indicators should be used to monitor the sustainability of UFT activities. They are increasingly recognized as decision support tools and are being employed to assess the progress toward the stated goals, evaluate the efficiency of government policies [2], measure changes in a consistent, effective, and relevant way [3], and monitor and report the sustainability of UFT companies. As defined by [4], an indicator is "a variable, or a combination of variables, selected to represent a certain broader issue or characteristic of interest." Several studies have introduced [5–9] indicators to assess sustainability in transport fields. In the literature, there is not a lack of assessment tools but a lack of unification of those approaches. There are neither a standardized selection approach nor a set of standardized indicators to assess transport sustainability. The main objective of this paper is to select sustainability indicators for UFT. The following research question are addressed in the remainder of this paper:

- How important is the use of indicators in evaluating the sustainability of a transport system?
- Which indicators should be used for assessing urban freight transport sustainability?
- What are the sustainability dimensions associated with these indicators?
- Do we have a standard list of indicators?
- What is the methodological approach that can be employed to select sustainability indicators?
- Which indicators can provide a comprehensive overview of the freight transport system?

This paper is organized as follows. The next section reviews the existing approaches for selecting sustainability indicators. Section 3 presents the approach introduced to select indicators of UFT. Finally, the conclusion and future research directions are summarized in Section 4.

2. Literature Review

2.1. Existing Approaches

The coronavirus disease (COVID-19) that emerged in early 2020 has negatively impacted all sectors, especially freight transport activities. It has reduced the demand for transport services and worsened the financial situation of the freight transport sector, leading to a decline in transport activities and in the spatial connection of UFT. To address these challenges, companies need to enhance their operational efficiency for informed decision-making, as transport activities have become less sustainable during the COVID-19 pandemic. Consequently, it is crucial to understand the impact of this crisis on UFT and the issues related to its sustainability. In this context, indicators play a crucial role in helping actors assess the current transport situation and develop good practices [10]. Ref. [11] defined a set of indicators to support companies in monitoring the sustainability of transport. Similarly, Ref. [12] presented a set of sustainability indicators drawn from the literature to facilitate transport planning processes. Ref. [13] introduced indicators to assess urban sustainability using the Delphi method. Specifically, in 2011, Ref. [14] suggested economic indicators to assess freight transport. Ref. [15] also developed a set of indicators to support tactical and operational decisions in urban logistics, focusing on the direct impacts of urban logistics activities on sustainability. Ref. [16] proposed an indicator selection approach based on properties as well on causal chains and networks, using 32 indicators to assess sustainable mobility in Indian cities. Ref. [17] presented a set of transport sustainability indicators for the development of policy strategies. They chose a set of indicators from the literature based on properties. Ref. [18] narrowed down to a shortlist of five key performance indicators—congestion, accidents, air pollution, noise pollution, and land use—to measure the sustainability of urban transport. A review by [19] defined indicators to assess urban logistics sustainability according to the aforementioned traditional dimensions. Ref. [20] presented a set of sustainability indicators for UFT with an operational objective, assessing the indicators internally with the participation of five experts within their academic research unit. The indicator selection process involved six properties. Ref. [21] provided an overview of spatial indicators of freight transport and urban logistics, summarizing different research works which combined indicators with attractiveness or accessibility measures and explicitly addressed UFT or the activities generating these transport flows. Additionally, Ref. [22] conducted a literature review identifying the most commonly used transport indicators according to traditional dimensions. From this review, the authors observed a growing interest in assessing transport indicators. Ref. [23] introduced indicators to help transport stakeholders assess urban plans and alternative infrastructure designs, selecting indicators based on three properties and expert consultation. Ref. [24] chose 33 transport sustainability indicators based on traditional dimensions, drawing from 21 articles and properties.

2.2. Methods Used in Selecting Indicators

We observe that the majority of researchers in the studies presented above have focused on selecting indicators for public transport, as this field has been extensively examined in the literature. However, only Refs. [15,19–21] have defined indicators to assess the sustainability of freight transport. It is evident that the number of selected indicators varies from one study to another. Given the absence of a defined number, it is advisable to use a manageable set of indicators and refrain from employing a small number of unrealistic indicators that may not adequately represent all dimensions of sustainability [25,26].

Different methods were employed for indicator selection. One of the most frequently used methods involves selecting indicators from the previous literature, drawing on relevant studies about assessing UFT sustainability. Other authors, such as Ref. [13] selected indicators based on the Delphi method. The latter was designed to obtain a consensus from a group of experts by answering a questionnaire in an iterative way. The majority of past studies applied a multi-criteria analysis (MCA) method, relying on properties to select indicators. Other researchers consulted experts to refine their analysis. Refs. [11,16] selected the indicators based on causal relationships. Among these methods, it is evident that multi-criteria analysis is more objective, systematic, and efficient in terms of time consumption and human resources compared to the Delphi method. The causal chain framework was used to structure problems into causal relationships, but it lacks flexibility and faces challenges in representing relationships between problems within a causal framework.

3. Methodology: Selecting Indicators of UFT

Several indicators have been proposed in the literature to assess transport sustainability. Each chosen indicator must explicitly correspond to each dimension of sustainability, presenting a representative scenario of UFT. It should also be defined according to the potentially conflicting interests of both private and public actors.

In this paper, we present an approach to selecting sustainability indicators to assist decision-makers in assessing UFT sustainability. The originality of this research lies in the selection of a set of indicators used to illustrate the multidimensionality of UFT sustainability. Figure 1 presents the process of selecting UFT indicators. The various steps of the proposed approach are detailed below:

- Step 1 involves identifying a long list of indicators to assess UFT sustainability based on those introduced in the literature. These indicators are then categorized according to the sustainability dimensions selected in [27].
- Step 2 corresponds to selecting the most commonly used properties and extracting a reduced set of sustainability indicators.
- Step 3 consists of presenting in detail each selected sustainability indicator for the five dimensions above.

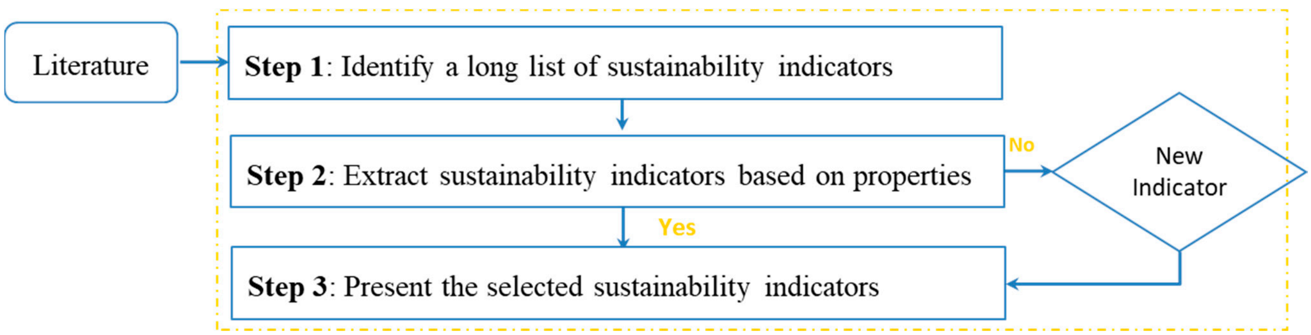

Figure 1. Selecting sustainability indicators of UFT.

The selection of a set of UFT sustainability indicators can be broken down into three steps. Initially, a long list of indicators based on the five dimensions of Ref [27] is created.

Secondly, a set of sustainability indicators is extracted according to five properties. Finally, all the selected sustainability indicators are presented.

3.1. Long List of Sustainability Indicators

The main objective of this paper is to extract widely employed UFT indicators from the literature. After analyzing the literature review presented in our previous work [28], only the most frequently cited articles are considered. Ref. [28] outlined the approaches to assessing sustainability in the field of freight transport between 2002 and 2022. In total, our literature review includes 61 articles, of which 41 are excluded after analysis, retaining the most frequently referenced approaches. Potentially relevant sustainability indicators for UFT, as presented in these approaches, are retained. A total of 83 indicators are identified to assess the sustainability of UFT. These indicators are then classified according to five dimensions (economic, environmental, social, political, and spatial) (cf. Figure 2), as outlined in research work [27].

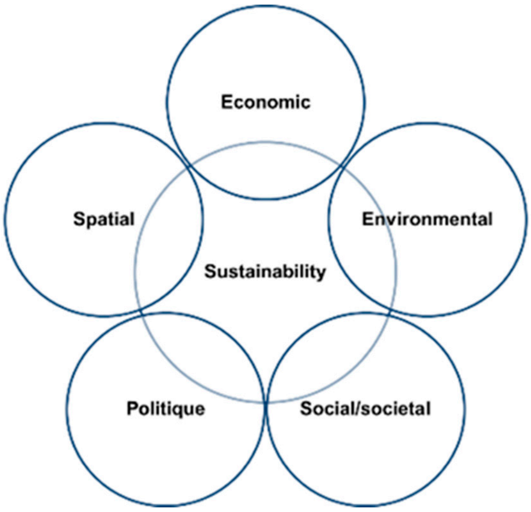

Figure 2. Five sustainability dimensions [27].

The majority of approaches, according to our literature review, concentrate solely on sustainability, considering all of its three dimensions (economic, environmental, and social) (cf. Table 1). From the literature review, we conclude that the traditional dimensions do not comprehensively address sustainability aspects and are, therefore, insufficient to reflect the real behavior of UFT. It is also observed that some additional dimensions are already encompassed in the traditional ones, while the political and spatial dimensions are equally important for various reasons.

Table 1. Sustainability dimensions in the existing approaches.

Reference	Dimensions			
	Economic	Environmental	Social/Societal	Others
[11]	*	*	*	
[12]	*	*	*	
[14]	*	*	*	Mobility
[15]	*	*	*	
[18]	*	*	*	
[16]	*	*	*	Activity
[17]	*	*	*	
[21]	*	*	*	Spatial
[19]	*	*	*	
[20]	*	*	*	Political

Table 1. *Cont.*

Reference	Dimensions			
	Economic	Environmental	Social/Societal	Others
[22]	*	*	*	
[23]	*	*	*	
[24]	*	*	*	
[27]	*	*	*	Spatial and political

*: The article which considers this dimension.

Our proposal is to expand the traditional dimensions of freight transport to include crucial dimensions for sustainability evaluation. For sustainable decisions, we suggest considering not only the traditional dimensions (i.e., economic, environmental, and social/societal dimensions) but also the political and spatial ones. These dimensions are inseparable, complementary, and fundamentally interdependent. More precisely, they must be interconnected and combined to create a stable foundation. In this context, the fourth political dimension is introduced, representing the awareness of and impact on sustainable transport required of local authorities. Freight transport should be more flexible in terms of political strategy and has to adapt to various circumstances by providing support in times of crisis. The policies implemented by governments and transport authorities have a significant impact on the improvement of sustainability. Additionally, the spatial dimension should be considered in the assessment of UFT to reduce congestion and accessibility problems. These dimensions are defined below.

- The economic dimension is crucial for private actors seeking to maximize profit and for public actors aiming to minimize the investments granted to transport. This dimension should be considered to reduce UFT operational costs.
- The environmental dimension addresses the need to preserve the environment during UFT activities. It conserves resources, reduces pollution, and prevents climate change to preserve environmental integrity for present and future generations.
- The social/societal dimension is related to UFT safety conditions and concerns the value of human resources, their health, and satisfaction. This dimension considers safety and security measures.
- The political dimension represents the awareness of local authorities regarding sustainable transport. It refers to policies initiated to regulate freight transport to achieve sustainability in this sector.
- The spatial dimension is particularly important in the assessment of UFT to provide a reference framework for national and regional interventions and actions. This dimension introduces the perspective of a spatially equitable, efficient, and coherent territory.

Table 2 illustrates the sustainability indicators used in the most frequently referenced approaches. It also demonstrates that the range of indicators is broader in the three traditional dimensions, and very few approaches are based on the political and spatial dimensions.

Table 2. Indicators of UFT sustainability.

Dimension	Indicator	[11]	[12]	[29]	[14]	[26]	[15]	[30]	[4]	[18]	[16]	[20]	[19]	[21]	[31]	[32]	[33]	[34]	[22]	[23]	[24]
Traditional dimensions, Economic	Modal split		*		*							*							*	*	
	Loading rate						*					*	*		*	*	*				
	Service rate		*										*								*
	Congestion		*		*		*	*		*									*		
	Congestion intensity (Road occupancy rate)											*		*							*
	Length of congestion											*								*	
	Off-peak system performance											*									
	Volume of freight moved (Ton-km)	*		*	*			*					*								
	Intermodal transport intensity (Ton-km)	*			*																
	Road transport intensity (Ton-km)	*			*									*						*	
	Rail intensity (Ton-km)	*			*															*	
	Distance traveled (km)	*			*						*		*								
	Transport costs	*				*					*			*	*				*		
	Logistics costs						*														*
	Operational costs						*							*							*
	Land consumption for transportation infrastructure	*	*			*				*									*		
	Investment in infrastructure						*	*			*	*									
	Number of loading and unloading facilities						*	*				*				*					
	Logistics reliability rate							*									*				*
	Economic development: staff training							*								*	*				
	Financial viability						*	*	*				*			*		*			*
	On-time service rate (%)	*					*						*	*		*					
	Net margin (EUR, $, %)						*						*								
	Internal rate of return						*						*			*					
	Costs							*								*	*				
	Economic growth							*								*					
	Staff training costs															*					
	Number of vehicles by type	*		*							*	*		*					*	*	
	Number of transport jobs						*		*												
	Road occupancy time of stopped vehicles	*												*							*
	Total transport time													*							*

Table 2. *Cont.*

Dimension	Indicator	[11]	[12]	[29]	[14]	[26]	[15]	[30]	[4]	[18]	[16]	[20]	[19]	[21]	[31]	[32]	[33]	[34]	[22]	[23]	[24]
Environmental	GHG emissions	*	*		*	*	*					*	*	*	*				*		*
	Air pollutants emissions (PM2.5, PM10, . . .)		*	*		*	*								*				*		*
	PM2.5 (Particulate matter)				*							*		*							
	PM10 (Particulate matter)				*							*	*	*							
	O_3 (Ozone)				*									*							
	NOx (Nitrogen oxides)	*			*							*	*	*							
	SOx (Sulfur oxides)	*			*								*	*							
	CO (Carbon monoxide)	*																			
	CO_2 (Carbon dioxide)	*		*	*																*
	N20 (Nitrous oxide)				*																
	VOC (Volatile organic compounds)	*			*								*	*							
	CH4 (Atmospheric methane)	*			*																
	NH3 (Ammonia)													*							
	emissions							*	*	*	*	*		*		*	*	*			
	Energy consumption	*	*	*	*	*	*	*			*	*	*	*	*	*		*	*	*	*
	Sustainable freight vehicles								*										*		
	Climate changes	*						*								*					
	Consumption of renewable energy		*					*	*					*		*	*	*	*		*
	Impact on noise level		*						*										*		*
	Depletion rate of natural resources (%)	*									*										*
	Land consumption								*		*								*	*	
	Land use planning											*									
	Vibration level															*					*
Social/societal	Noise	*		*	*					*	*	*		*	*	*	*	*			
	Accidents	*	*	*	*					*		*				*				*	*
	Fatalities	*	*		*	*		*				*			*				*	*	*
	Injuries	*			*	*		*				*			*	*				*	*
	Freight transport personnel certification																				
	Safety							*	*		*	*							*		
	Congestion									*	*		*	*							*
	Average speed in the city																				*
	Employee satisfaction rate												*			*					
	Customer satisfaction rate						*						*			*		*			
	Job creation rate				*		*						*					*			
	Accessibility and connectivity	*						*	*		*					*			*	*	

Table 2. *Cont.*

Dimension		**Indicator**	[11]	[12]	[29]	[14]	[26]	[15]	[30]	[4]	[18]	[16]	[20]	[19]	[21]	[31]	[32]	[33]	[34]	[22]	[23]	[24]
		Equity		*	*				*	*		*					*					
		Health and respiratory problems due to freight transportation	*			*											*					
		Quality of life							*								*	*				
		Use of information and communication technologies															*	*				
		Stakeholder participation rate																*				
		Health impact (Negative effect: perceived risks and hazards)		*													*	*		*		*
		Vehicle evaluation											*									
		Mental accessibility																				*
Emerging dimensions	Political	Financial resources											*									
		Human resources											*									
		Sustainable policies											*									
		Sustainable business											*									
		Spatial restriction																				
		Temporal restriction																				
	Spatial	Peripheral infrastructure capacity													*							
		Nodal infrastructure capacity													*							
		Accessibility																				

*: this indicator is considered in the reference.

3.2. Properties

The approaches proposed by [12,14,16,17,20,22–24] used properties to select the appropriate indicator. Several properties were employed to examine the applicability of indicators in different domains for specific purposes. The number of employed properties (e.g., achievability, data availability, contextuality, independence, measurability, opportunity, practicability, predictability, relevance, representation, sensitivity, simplicity, and understanding) varied from one approach to another. These proprieties are presented in Table 3.

Table 3. Properties of the selection of the most commonly used indicators.

Property	Description	References
Achievability	An indicator is achievable at a reasonable cost using an appropriate collection method.	[22,35]
Contextuality	An indicator appropriate to the context of study combines the properties of transparency, interpretation, target relevance, and actionability.	[36]
Data availability	Data should be available or can be rendered using scientifically approved tools.	[22,29]
Independence	The indicators must be independent of each other.	[26,37]
Measurability	An indicator can be measured in a simple and understandable way providing valuable information on the sustainability of transport.	[16,29,35]
Opportunity	An indicator needs to be collected and reported at the right time to influence the decision-making process.	[4,29,35]
Practicality	A practical indicator addresses the properties of measurability, data availability, and ethical concerns.	[36]
Predictability	The predictability of indicator values is crucial to help transport actors' current situation and propose good practices.	[38]
Relevance	An indicator should be adequately selected to achieve a pre-defined goal and should provide an overview about the studied situation considering relevant information.	[16,35,38]
Representation	A representational indicator combines the properties of validity, reliability, and sensitivity.	[36]
Sensitivity	An indicator must be sufficiently sensitive to write the purpose of the study.	[39,40]
Simplicity	An indicator should be related to the simple and specific conditions that the project seeks to change and be easily understood by transport actors.	[29,35,40]
Understanding	Understanding an indicator is important in facilitating discussions between experts and transport stakeholders.	[37,41]

The use of appropriate properties facilitates the selection process. In this context, we selected the most relevant properties to be used when selecting indicators. The chosen properties are achievability, data availability, predictability, relevance, and understanding. In this study, we identify the sustainability indicators of UFT by assessing a long list of indicators based on the five properties defined below:

- Achievability is crucial to obtaining the necessary information on the actual situation of an indicator at a reduced cost and in the shortest time. Indicators that are not achievable are scored "0".
- The property of data availability ensures an efficient and rapid evaluation of a given indicator. Certain surveys and data collection processes should be conducted in some cases, especially when there is a lack of information about the indicator. The latter is scored "0" if data cannot be collected. An indicator that is scored "1" is either readily available for use as a census or requires simple models to collect information or conduct surveys.
- An indicator should be predictable to allow private and public actors to act quickly. The predictability of an indicator helps one to predict future situations and identify the appropriate interventions for achieving a sustainable UFT. An indicator is considered predictable if scored "1" and unpredictable if scored "0".
- The fourth property concerns the relevance of an indicator to describing UFT. The irrelevance of an indicator provides erroneous interpretations and, subsequently, may lead to bad decisions. The relevant indicator is denoted by "1".

- The fifth property concerns the understanding of an indicator. The easy understanding of an indicator facilitates its execution by freight transport actors. An indicator should provide clear information about the studied situation and the purpose of the study. An indicator is considered understandable if scored "1" and not understandable if scored "0".

For all the properties, the indicators are scored using a binary scale. The indicators selected from the long list are those that do not receive a score of "0" for any property. We use a non-compensatory conjunctive method because it is simple compared to other more complex methods. This multi-criteria analysis can be easily applied by decision makers. Conceptually, we can distinguish between compensatory and non-compensatory approaches when modeling choice behavior. In a compensatory decision-making process, the lower utility (evaluation, satisfaction, etc.) due to a particular attribute of the alternative can be compensated by the higher utility derived from one or more of the alternative's remaining attributes.

In the case of a non-compensatory decision-making process, it is assumed that no such compromise is made. Instead, attributes are typically evaluated on an attribute-by-attribute basis. If an alternative selection is not accepted on this basis, it will not be selected, regardless of the utility it derives from other attributes. For those reasons, a non-compensatory conjunctive method is used in this study. The indicators are rated using a binary scale. The principle of the non-compensatory conjunctive method is that all properties considered for choice are accompanied by one or more mandatory conditions. Failure to comply with one of these conditions for one of the properties results in the rejection of the indicator concerned. For example, an indicator must receive a score of "1" for all five properties; otherwise, it must be at once predictable, relevant, understandable, and achievable and have easily available data.

3.3. The Selected Sustainability Indicators

After the analysis of the literature [28], Table 2 presents only the most frequently referenced and relevant articles, resulting in a long list of 83 identified indicators. Following the evaluation of the long list, we retain 18 sustainability indicators for UFT using the non-compensatory conjunctive method. The selected indicators are those that do not score a value of "0" for any property and have been identified by at least two experts. In this section, we present the eighteen UFT sustainability indicators, organized into three economic indicators, four environmental indicators, five social/societal indicators, four political indicators, and two spatial indicators, constructed across five dimensions. The selected set of UFT sustainability indicators is detailed in Table 4.

Table 4. Set of the selected indicators of UFT sustainability.

Dimension		Indicator
Economic	EC1	Modal split
	EC2	Loading rate
	EC3	Congestion
Environmental	EN1	GHG emissions
	EN2	Air pollutants emissions (PM2.5, PM10, NOx, . . .)
	EN3	Energy consumption
	EN4	Sustainable freight vehicles
Social/societal	SO1	Accidents
	SO2	Fatalities
	SO3	Injuries
	SO4	Noise
	SO5	Freight transport personnel certification

Table 4. *Cont.*

Dimension		Indicator
Political	PO1	Financial resources
	PO2	Sustainable businesses
	PO3	Spatial restriction
	PO4	Temporal restriction
Spatial	TE1	Peripheral infrastructure capacity
	TE2	Nodal infrastructure capacity

3.3.1. Economic Indicators

The selected economic indicators aim to enhance the mobility of freight. Table 5 presents the selected economic indicators. The modal split of UFT is an economic indicator defined using the percentage share of each mode of freight transport, measured in tons-kilometers (Tons-Km) [12,42]. This indicator's relevance lies in both environmental and economic sustainability, particularly when compared to other less sustainable modes of freight transport. Many cities monitor the modal split to ensure the sustainability of UFT and gauge the success of their mobility policies. To measure this indicator, follow the following steps:

- Determine the Total Tons-Kilometers: Calculate the total distance in tons-kilometers for all modes of freight transport. This involves multiplying the weight of goods transported by the distance traveled for each mode.
- Calculate the Modal Split Percentage for Each Mode: For each mode of transport (road, rail, sea, air, etc.), calculate its percentage share of the total tons-kilometers value.
- Interpretation: The resulting modal split percentage for each mode will provide insights into the distribution of freight transport, indicating the proportion of total freight carried by each mode.

Table 5. The selected economic indicators.

		Indicator	Definition	Objective	Unit
Economic	EC1	Modal split	The share of each mode of freight transport in the total transport.	Improve mobility	Tons-Km
	EC2	Loading rate	The occupancy rate of freight transport vehicles and their loading capacities.		%
	EC3	Congestion	The average daily peak congestion per lane mile of the motorized transport.		Km/h

The loading rate is an economic indicator of UFT. A higher rate signifies a better sustainability for UFT. This rate is expressed by the maximum load capacity in weight that can be transported in the vehicle and by the load capacity in volume. The loading rate can be further improved by adjusting the weight and/or volume of the transported products. To measure this indicator, follow the steps below:

- Maximum Weight-Carrying Capacity: This is the maximum weight of goods that the vehicle is capable of transporting in a single load. This measurement is typically expressed in tons.
- Volume-Carrying Capacity: This represents the maximum volume of goods that the vehicle can accommodate in a single load. The measurement is often expressed in cubic meters or any other relevant volume unit.
- Loaded Vehicle Travel Rate: This expresses the percentage of the maximum load capacity utilized during transportation.

Freight transport contributes to congestion, especially in city centers. In this context, congestion is assessed as an indicator using the travel time during peak hours, the traveled distance, and the congestion intensity. To measure the congestion, follow the steps below:

- Total Daily Congestion Kilometers: Measure the total distance of congestion during daily peak hours. This can be obtained by analyzing specific road segments where congestion is observed.
- Total Kilometers of Motorized Transport Lanes: Calculate the total length of all motorized transport lanes during the analysis period.
- Calculation of Average Kilometric Congestion: Divide the total daily congestion kilometers by the total kilometers of motorized transport lanes.

3.3.2. Environmental Indicators

The selected environmental indicators are assessed to reduce pollutant emissions and improve energy efficiency. Table 6 presents the chosen environmental indicators.

Table 6. The selected environmental indicators.

		Indicator	Definition	Objective	Unit
Environmental	EN1	GHG emissions	The amount of GHG emitted by freight vehicles.	Reduce pollutant emissions	kg CO_2 eq.
	EN2	Air pollutants emissions (PM2.5, PM10, NOx, . . .)	The amount of pollutants (PM10, PM2.5 and NOx) emitted by freight vehicles.		kg PM10 eq.
	EN3	Energy consumption	The average amount of energy consumed by freight vehicles.	Improve energy efficiency	MJ/100 Km
	EN4	Sustainable freight vehicles	The number of sustainable freight vehicles compared to that of non-sustainable vehicles.		%

Air pollutants, which have a detrimental impact on urban areas, are more prevalent in the transportation sector. Additionally, the expansion of freight transport contributes to increased emissions of various pollutants. Greenhouse gas (GHG) emissions, resulting from the carbon oxidation during the combustion of fossil fuels, escalate with the rise in transport volumes. These emissions are typically expressed in kilograms or tons of CO_2 equivalent [43]. The indicator for greenhouse gas (GHG) emissions from freight transport vehicles is generally calculated by measuring the total quantity of GHGs emitted by these vehicles, expressed in kilograms of carbon dioxide equivalent (kg CO_2 eq). This indicator offers insights into the environmental impact of emissions from freight transport, aiding in the assessment and monitoring of the carbon footprint associated with these activities.

Freight transport results in significant emissions of particulate matter (PM2.5/PM10) and nitrogen oxides (NOx) [44]. Therefore, measuring emissions from UFT activities is crucial for estimating their impact on the environment. Thus, GHG emissions and air pollutants emissions (PM2.5, PM10, NOx, . . .) are considered two important environmental indicators. For air pollutants emissions (PM2.5, PM10, NOx, etc.), the calculation of the indicator involves measuring the total quantity of these pollutants emitted into the atmosphere. This quantity is often expressed in specific units associated with each pollutant.

Furthermore, it is advisable to include an indicator for reducing energy consumption in freight transport across all phases of vehicle, infrastructure, and building construction, use, and end of life. The average energy consumption of freight vehicles is calculated by measuring the total amount of energy consumed by these vehicles to cover a specific distance. This indicator provides insight into the energy efficiency of freight vehicles, expressing the amount of energy required to transport goods over a given distance.

Quantifying environmental damage and its effects on human health is challenging. To identify and quantify this damage, sustainable freight vehicles are chosen as an indicator of UFT. The use of sustainable vehicles helps reduce noise and air pollutant emissions. It also minimizes energy consumption by employing more environmentally-friendly alternatives. These vehicles can be tricycles or electric vehicles with different capacities, lengths, and speeds depending on their load or alternative-fuel vehicles. Therefore, increasing the use of sustainable freight vehicles is recommended. This indicator is calculated by establishing the ratio between the number of sustainable vehicles and the total number of vehicles and then expressing this ratio as a percentage.

3.3.3. Social/Societal Indicators

The selected social/societal indicators are utilized to enhance safety levels, reduce noise pollution, and improve security. Table 7 presents the chosen social/societal indicators.

Table 7. The selected social/societal indicators.

		Indicator	Definition	Objective	Unit
Social/societal	SO1	Accidents	The number of traffic-related accidents in relation to the total number of accidents.	Improve the level of safety	Number of accidents
	SO2	Fatalities	The number of traffic-related fatalities in relation to the total number of inhabitants.		Mortality/inhabitants
	SO3	Injuries	The number of traffic-related injuries in relation to the total number of inhabitants.		Injured persons/inhabitants
	SO4	Noise	Freight vehicles within noise limits versus the total number of freight vehicles.	Reduce noise pollution	Db
	SO5	Freight transport personnel certification	The number of certified freight transport personnel in relation to the total number of freight transport personnel.	Improve the level of security	%

UFT, especially by trucks, poses high risks of accidents. To enhance safety in urban freight transport, three indicators are employed: accidents, fatalities, and injuries. The accident indicator represents the percentage of road accidents compared to the overall number, offering insights into the prevalence of road-related incidents in the total count. The fatality indicator expresses the ratio of traffic-related fatal accidents to the total population, providing a measure of deaths per capita resulting from such accidents. The injury indicator represents the ratio of traffic-related injuries to the total population, offering insights into the injuries per capita resulting from traffic incidents.

Noise pollution resulting from UFT operations is a significant concern for both citizens and employees, with adverse impacts on human health. It can lead to stress, sleep disorders, cardiovascular diseases, and hearing loss. In 2018, the World Health Organization (WHO) recommended that noise pollution levels should not exceed 53 decibels during the day and 45 decibels at night. The measurement of a noise transport indicator involves assessing the noise levels generated by transportation activities, typically quantified in decibels.

To ensure social sustainability, the certification of freight transport personnel is a crucial requirement. Through training and certification, personnel can enhance their knowledge and awareness, ultimately contributing to road safety. As such, freight transport personnel certification is considered a social indicator that benefits employers, personnel, customers, and citizens by improving the quality of the provided service and increasing individual satisfaction rates. This indicator is calculated by establishing the ratio between the number of certified freight transport personnel and the total number of freight transport personnel and then expressing this ratio as a percentage. It offers insights into the percentage of certified personnel within the overall workforce in freight transport, reflecting the level of certification within the industry.

3.3.4. Political Indicators

Political indicators influence the political interventions that can be implemented by both public actors and industrialists. The selected political indicators ensure financial efficiency and progress toward sustainable businesses. They also enhance the effectiveness of public policies. Table 8 presents the selected political indicators.

Table 8. The selected political indicators.

		Indicator	Definition	Objective	Unit
Political	PO1	Financial resources	The budget of sustainable UFT projects compared with that of the total transport.	Ensure financial efficiency	%
	PO2	Sustainable businesses	The number of ISO 14001-certified companies compared with the total number of companies.	Move towards sustainable businesses	%
	PO3	Spatial restriction	Compliance rate with spatial traffic and parking restrictions.	Improve the effectiveness of public the policies	%
	PO4	Temporal restriction	Compliance rate with temporal traffic and parking restrictions.		%

The resource indicator should be considered to evaluate the involvement of local authorities in competitive projects. Financial resources represent the allocation of resources to sustainable UFT projects in comparison to the overall transport budget. The indicator for financial resources in UFT projects is calculated by establishing the ratio between the budget allocated to UFT projects and the total transport budget and then expressing this ratio as a percentage.

The sustainable business indicator refers to the ISO 14001 [45] (environmental management systems) applied at the company-policy level. These systems encompass comprehensive, systematic, planned, and documented environmental programs initiated to reduce the adverse effects of businesses on the environment. The sustainable business indicator is calculated by establishing the ratio between the number of businesses certified with ISO 14001 and the total number of businesses and then expressing this ratio as a percentage.

The applicability of government regulations ensures sustainable UFT by addressing aspects such as freight traffic, environmental protection, and road safety. Two major indicators are selected for assessment. The first indicator is spatial restriction, while the second is temporal restriction, implemented through the introduction of time windows for UFT. The spatial restriction indicator is calculated by determining the compliance rate with spatial restrictions on traffic and parking. This indicator provides insights into the extent to which spatial restrictions on traffic and parking are adhered to, expressed as a percentage of compliant observations relative to the total number of observations. The temporal restriction indicator is calculated by establishing the compliance rate with temporal restrictions on traffic and parking. This indicator provides insights into the extent to which temporal restrictions on traffic and parking are adhered to, expressed as a percentage of compliant observations relative to the total number of observations.

3.3.5. Spatial Indicators

Improving the spatial accessibility of both nodal and peripheral infrastructures ensures the sustainability of UFT. Two accessibility indicators are used to determine the spatial capacity of the infrastructure accessible to freight transport. Table 9 presents the selected spatial indicators.

Table 9. The selected spatial indicators.

		Indicator	Definition	Objective	Unit
Spatial	TE1	Peripheral infrastructure capacity	The percentage of the capacity and availability of peripheral infrastructures.	Ameliorate peripheral accessibility	%
	TE2	Nodal infrastructure capacity	The percentage of the capacity and availability of nodal infrastructures.	Enhance nodal accessibility	%

Peripheral accessibility concerns the number of connected linear infrastructures spatially covering different industrial and economic exchange areas. Estimating peripheral infrastructure capacity (in the number of vehicles or available travel time) helps actors improve peripheral accessibility [21], hence its name, “spatial indicator”. The latter allows actors to verify the balance between infrastructures and propose planning and dimensioning actions that guarantee territory development. This indicator measures the degree of compliance with spatial restrictions regarding traffic and parking. It assesses the extent to which vehicles adhere to defined rules and the limits for their movement and parking in specific areas.

Nodal accessibility refers to the spatial adequacy between nodal infrastructures (platforms, logistics terminals, and loading and unloading areas) and urban freight transport activities. It helps urban planners and companies reach a consensus on the planning strategy for freight infrastructure. Indeed, nodal infrastructures are spaces that ensure the storage, loading, and unloading movements of the freight. However, certain constraints limit the efficiency of these spaces. Instances of these constraints include the lack of infrastructure (given that, with the dynamics of economic activity, maintaining the supply of these spaces is a challenge for the managers and actors of UFT), the lack of control and monitoring of these spaces, and the inappropriate choice of configurations, including the poor dimensioning and/or poor location of these spaces. The nodal infrastructure capacity is selected as a spatial indicator by defining the capacity and availability of this infrastructure for the proper planning and organization of routing problems [21]. Finally, this indicator defines the infrastructure limits imposed on the traffic flow and nodal accessibility. This indicator measures the level of compliance with time-based restrictions on traffic and parking. It assesses how well vehicles adhere to specific time-related rules, such as the hours during which traffic or parking is allowed or prohibited.

4. Research Implication

Firstly, the proposed approach involves compiling a comprehensive list of sustainability indicators derived from the literature. This necessitates filtering, analyzing, discussing, and validating the initial set of indicators through experts, considering five key properties. The obtained results carry significant theoretical and managerial implications for the stakeholders involved. The managerial contributions of this research can be summarized as follows:

- The proposed approach empowers stakeholders in freight transport to effectively monitor the sustainability of UFT, thereby bolstering economic, environmental, social, political, and spatial sustainability.
- It enables stakeholders to assess the current state of UFT sustainability according to selected indicators.
- The developed indicators offer UFT companies a valuable tool for evaluating the sustainability of their operations.

In contrast, the theoretical contributions are outlined as follows:

- The study presents eighteen indicators aimed at enhancing the sustainability of UFT.
- The proposed approach assesses sustainability across five dimensions—economic, environmental, social/societal, political, and spatial—thereby making a noteworthy contribution to the current body of literature.
- The suggested indicators serve as a valuable reference for assessing the sustainability of UFT.

5. Conclusions

Currently, most cities are striving to address the intensification of freight transportation, particularly the influx of a large number of trucks in city centers. The current objective, therefore, is to resolve various issues in freight transport while ensuring sustainability. In this context, this research introduced sustainability indicators for UFT. The list of sustainability indicators was developed in three steps. First, a long list of indicators for assessing the sustainability of UFT was compiled, identified through an extensive literature review. Subsequently, the most commonly used properties were selected. Following this, a non-compensatory conjunctive method was employed to streamline the long list of sustainability indicators from 83 to 18. These indicators were categorized into five dimensions: economic, environmental, social, political, and spatial.

Transport actors and other decision-makers could formulate plans to address issues, mediate conflicts, and transform systems by presenting a range of alternatives. Indicators can also assist decision-makers in selecting the optimal solution for meeting specific objectives. These indicators serve as tools facilitating communication between private and public actors to reach a compromise for priority improvements. This approach assesses the sustainability of urban freight transport while taking into account the local economic, environmental, social, political, and spatial development situation of the studied city.

This study has certain inherent limitations that warrant consideration in future research related to the assessment of freight transport sustainability. The results derived from indicators depend on data obtained from publicly available sources. Consequently, the precision of these results is contingent upon the quality and accessibility of the data.

Given the multi-dimensionality of the set of indicators, aggregating these indicators into a composite indicator facilitates the decision-making process. In this context, we propose, in our future research, an assessment approach for urban freight transport sustainability based on a composite indicator with sustainability perspectives. We also suggest that future research should focus on integrating resilience considerations and sustainability into urban freight transport. This involves a comprehensive decision analysis process, by including resilience assessment indicators.

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