Sustainability indicators for sustainable transport infrastructure development

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Abstract

To preserve resources for future generation, there is rising agreement that transportation system sustainability should capture attributes of system effectiveness and system impacts on economic development, environmental integrity, and social quality of life. To make the region sustainable, sustainability assessment can be incorporated at the planning level in order to influence decision making, and support policies. This paper present a review on methodologies that can be applied in sustainability assessment in transportation planning which can be used to incorporate sustainability more effectively in the planning process. This review on research study is potentially useful to road and transport infrastructural development agencies who are interested in understanding the range of tools and indicators being used for sustainability assessment, so that they can expand or refine their performance measures to capture sustainability in transportation planning, and using them in evaluating tradeoffs among challenging alternative as well as in identifying major alternative.

Key word: Sustainability indicator, road transport, assessment, planning

1.0 Introduction

Transport infrastructure like road, vehicle and people play a vital role in development of economy and employment for people. However their negative impact has adverse impact on society and future generation. Therefore rapid development of such infrastructure doesn’t sustainable picture of sustainable development. The word sustainable or sustainability has become a very controversial topic in road and transportation planning. Therefore many agencies are taking care of incorporating the definition even at regional and national scale planning level. World Commission on Environment and Development (WCED), 1987) provided definition of sustainability which is generally universally adopted world wide “Development that meets the needs of the present without com- promising the ability of future generations to meet their own needs’’. This definition is widely adopted by different researcher across globe.

From review of different research work carried out it can be observed that all the transportation sustainability indicators review was classified into the following four major categories: transportation system effectiveness-related, economic, environmental, and socio-cultural equity-related indicators. However, the present status of addressing sustainability in transportation planning indicate a higher focus on the effectiveness of transportation systems as well as the resulting environmental impacts (mainly air quality impacts), and less of a focus on economic and social impacts.

While there is no standard definition of sustainable transportation Jeon etl al, 2013 defined sustainable transportation system, as shown in Fig. 1 which depicts essential four elements that should be included in the attributes of a sustainable transportation system.

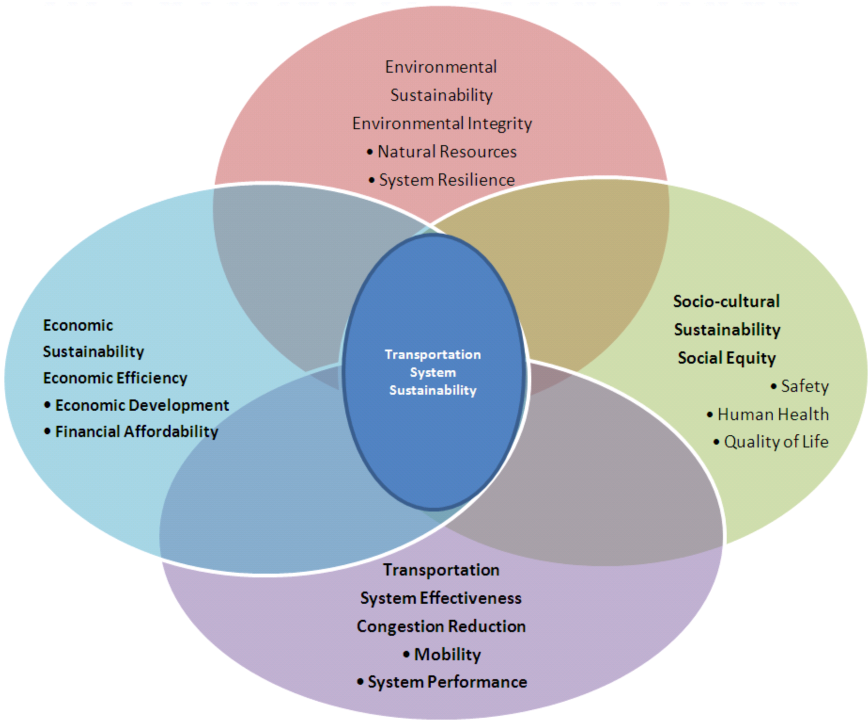

Fig. 1 Four essential factors of transportation system sustainability
(Source: C.M. Jeon et al.2013)

Considering a broader definition of transportation sustainability as improving the overall quality of life not just enhancing transportation systems, mission statements of about 40 percent of the State Departments of Transportation (DOTs) in the United States now include elements of sustainability (Jeon et al., 2010).

2. Current practices in sustainability assessment

Boyko et al., (2012) developed a toolkit for UK to facilitate the use of scenarios in any urban context and at any scale relevant to that context. The toolkit comprises two key components, namely, (i) a series of indicators comprising both generic and topic area-specific indicators (e.g., air quality, biodiversity, density, water) that measure sustainability performance and (ii) a list of characteristics (i.e., 1–2- sentence statements about a feature, issue or small set of issues) that describe four future scenarios. In combination, these two components enable to measure the performance of any given sustainability indicator, and establish the relative sensitivity or vulnerability of that indicator to the different future scenarios. An important aspect of the methodology underpinning the toolkit is that it is flexible enough to incorporate new scenarios, characteristics and indicators, thereby allowing the long-term performance of our urban environments to be considered in the broadest possible sense.

Lockwood (2013) assessed the forces working for and against the political sustainability of the UK 2008 Climate Change Act. The adoption of the Act is seen as a landmark commitment to action on climate change, but its implementation has not been studied in any depth. Recent events, including disagreements over the fourth carbon budget and the decarbonisation of the electricity sector, shows that while the Act might appear to lock in a commitment to reducing emissions through legal means; this does not guarantee political lock-in. An analysis of alternative sources of political durability was presented, drawing on a framework for understanding the sustainability of reform. It is argued that the Act has helped create major institutional transformations, although the degree to which new institutions have displaced the power of existing ones is limited. The Act has produced some policy feedback effects, especially in the business community, and some limited investment effects, but both have been insufficient to withstand destabilisation by recent party political conflicts. The Climate Change Act of United Kingdom remains at risk.

Jeon et al., (2010) used Multiple Criteria Decision Making (MCDM) approach for evaluating selected transportation and land use plans in the Atlanta US region using multiple sustainability parameters. A composite sustainability index was introduced as a decision support tool for transportation policymaking, where the sustainability index considers multidimensional conflicting criteria in the transportation planning process. They conducted a comprehensive literature review on sustainability indicators from sixteen different initiatives around the world, including North America, Europe, Australia, and New Zealand (Jeon and Amekudzi, 2005). The review indicated that while a standard framework for evaluating progress toward sustainability did not exist, similar to the existing definitions of transportation sustainability, there are still common themes and dimensions. Most of sustainability indicators in the literature have been defined using frameworks that may be categorized as: (1) linkages-based frameworks, (2) impacts-based frameworks, and (3) influence oriented frameworks. The existing and emerging evaluation frameworks in Atlanta attempted to capture at least one of the following: (1) the causal relationships that lead to progress toward or deviation away from sustainability, (2) the impacts of decisions on the three important areas that define sustainability, i.e., the economy, environment, and social well-being or quality of life, and (3) the level of influence or control that the responsible agencies have over the causal factors of sustainability. The review also provided an extensive list of indicators sorted by the relative frequencies with which they appeared in the sixteen initiatives.

Jeon and Amekudzi, (2005) addressed sustainability in transportation planning and provision seems to indicate a higher focus on the effectiveness of transportation systems as well as the resulting environmental impacts (mainly air quality impacts), and less of a focus on economic and social impacts.

Hart (1998) also identified four frameworks for organizing sustainability indicators: (1) category or issue lists, (2) a goal- indicator matrix, (3) driving force–state-response tables, and (4) endowment–liability–current result–process tables. Category or issue lists usually refer to organizing indicators based on the main focus of each indicator: the environmental, economic, and social aspects of the community. The goal-indicator matrix relates indicators to a range of sustainability issues or a set of community goals. Diving force–state-response tables balance measures of causes or driving forces; measures of the results, or state; and measures of programs and other human activities designed to alter driving forces with the goal of improving the state. This framework shares same essentials with the linkages-based framework identified in the prior review. The last framework uses endowments, liabilities, current results, processes as headings in a table that checks for balance among measures of what we are leaving for future generations, what we have now, and what is happening to create both situations (Hart, 1998). What is common to each framework is the creation of indicators around specific themes.

Zegras (2006) presented the sustainability indicator prism that innovatively represents the hierarchy of goals, indexes, indicators, and raw data as well as the structure of multidimensional performance measures. As shown in Fig. 2, the top of the pyramid represents the community goals and vision, the second layer represents a number of composite indexes around the selected themes, third layer represents indicators or performance measures building from raw data at the bottom of the pyramid. This concept can also be considered as the combination of Hart’s category or issue lists (environmental, economic, and social aspects) with the goal-indicator matrix, which organizes indicators/indexes around a set of community goals or various sustain- ability issues. This framework is especially helpful when decision makers first set the community goals for sustainability around the essential dimensions of sustainability (environmental, economic, and social dimensions, etc.) and indicators and composite indexes are constructed based on the categorized goals and objectives.

The critical points that emerge from these constructs are that performance measures must be developed to capture a community’s broader vision.

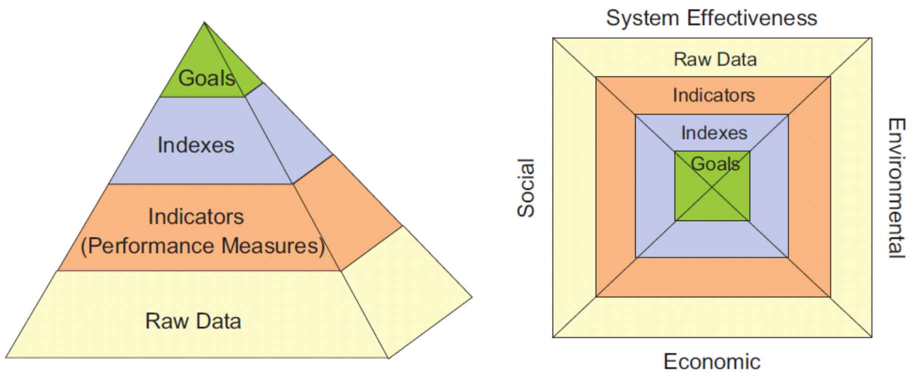

Fig. 2. Zegras’s sustainability indicator prism(adapted from Hart, 1998).

3.0 What is available for users or decision maker or planner?

Various tools and techniques such scenario planning; graphical models; system dynamics approaches; economic-based models; integrated transportation and land use models; simulation and decision analysis models; environmental impact analysis; and life cycle assessment (LCA) for qualitative analysis can be done to find sustainability of project. Apart from that there are many Quantitative sustainability models which have been applied in several European studies, including such models as SPARTACUS (Systems for Planning and Research in Towns and Cities for Urban Sustainability) and ESCOT (Economic Assessment of Sustainability Policies of Transport) initiatives. The SPARTACUS study uses an integrated transportation and land use model, MEPLAN, to evaluate the sustainability of selected transportation and land use scenarios.

Zietsman et al., (2003) used simulation and decision model which provides important insights for the integration of a sustainability evaluation process with a decision making process. They developed a single index for sustainable transportation from selected performance measures based on the multi-attribute utility theory (MAUT) technique. While these researchers mainly focus on quantifying the sustain- ability of selected corridor-level scenarios using a microscopic simulation model, CORSIM, the application of a multiple criteria decision making (MCDM) approach in the sustainability evaluation reveals the benefits of using indexes and is broadly applicable (Zietsman et al., 2003). Ideally, sustainability evaluation should incorporate broader impacts of transportation systems and model the necessary interactions among these multi-dimensions. These critical elements were important guiding principles in framing the methodology developed for the evaluation, and can be considered as important guiding principles in general in the development of analysis tools for sustainability assessment.

In another study by Jeon et a., (2013) considered sustainability in regional transportation planning using the following steps: (1) identifying pertinent sustainability issues and regional sustainability goals for the metropolitan region of interest, (2) defining relevant performance measures for transportation system sustainability based on the predetermined issues and goals, (3) analyzing and quantifying the comprehensive sustainability impacts of alter- native transportation and land use scenarios developed for the region, (4) constructing a Composite Sustainability Index (CSI) using the multiple criteria decision making (MCDM) theory, and (5) visualizing the sustainability indexes using a decision support tool in order to identify the most suitable plan for the predetermined sustainability-oriented objectives (Jeon et al., 2010).

Indicators developed by Jeon et al., (2013) is shown in Table 1 for existing metropolitan goals categorized into each dimension of sustainable transportation and the appropriate performance measures that can be used to assess each different goal for Atlanta Metro Politian Region in US. Each goal and objective is represented by one or more performance measures. It is worth mentioning that transportation system effectiveness is added to the three basic dimensions of sustainability because transportation mobility and system performance are indispensable components of transportation system sustainability.

In other study related to urban transport, Santos and Riberio (2013) used of sustainability indicators during the decision-making process for the case of Rio de Janeiro. They used set of 20 indicators which was selected and used as an example to evaluate their applicability to monitoring the lines of action regarding transportation in the Rio de Janeiro State Climate Plan. They found that that certain objectives cannot be monitored from the perspective of the sustainability criteria, and signal the importance of establishing monitoring criteria previously of public policy elaboration process. The use of the proposed indicators can help the public managers to monitor progress toward the goals presented in climate change policy for reducing greenhouse gas emissions and identify whether Rio de Janeiro is progressing toward sustainable development. Each indicator shows one aspect of sustainable transportation, as presented in Table 2. As it can be seen in Table 2, a set of 20 indicators was used to assess the sustainability of each transportation line of action, where applicable, as well as monitoring progress towards the goal of reducing GHG emissions. It is worth noting that the design of the actions presented in the Plan was not based on sustainability criteria, because the focus was on mitigating greenhouse gas emissions and the concept of sustainability was used as much broader perspective. Limitation of this Table 2 is that it makes the assessment on a qualitative basis.

Over a period of one hundred years the motor car has come to occupy a central role in all developed economies. It has trans formed our ability to travel easily and cheaply for work or leisure purposes, and it has changed the design of our urban spaces. Smith et al (2013) investigated the suitability of the Process Analysis Method (PAM) for measuring the sustainability of a transport system–a national car fleet delivering mobility in United Kingdom.

Table 1 Selected sustainability goals and performance measures
(Source : Jeon et al 2013)

Sustainability dimension	Goals and objectives	Performance measures
Transportation system effectiveness	A1. Improve mobility	A11. Freeway/arterial congestion
	A2. Improve system performance	A21. Total vehicle-miles traveled A22. Freight ton-miles A23. Transit passenger miles traveled A24. Public transit share
Environmental sustainability	B1. Minimize greenhouse effect	B11. CO_2 emissions B12. Ozone emissions
	B2. Minimize air pollution	B21. VOC emissions B22. CO emissions B23. NO_X emissions
	B3. Minimize noise pollution	B31. Traffic noise level
	B4. Minimize resource use	B41. Fuel consumption B42. Land consumption
Economic sustainability	C1. Maximize economic efficiency	C11. User welfare changes C12. Total time spent in traffic
	C2. Maximize affordability	C21. Point-to-point travel cost
	C3. Promote economic development	C31. Improved accessibility C32. Increased employment C33. Land consumed by retail/ service
Social sustainability	D1. Maximize equity	D11. Equity of welfare changes D12. Equity of exposure to emissions D13. Equity of exposure to noise
	D2. Improve public health	D21. Exposure to emissions D22. Exposure to noise
	D3. Increase safety and security	D31. Accidents per VMT D32. Crash disabilities D33. Crash fatalities
	D4. Increase accessibility	D41. Access to activity centers D42. Access to major services D43. Access to open space

Table 2: Applicability of indicators to evaluate the objectives regarding transportation presented in the Rio's climate change plan

Categories	Indicators	Transportation objectives — Rio's climate change plan						
		Expand quality of rail and subway	Expand use of BRT	Promote the use of sustainable biofuels	Programmes compulsory for bus passenger transport	Programme of captive and outsourced fleet vehicles	Inspection and maintenance programme for light vehicles	Biodiesel based on the reutilisation of vegetable oils programme
Environment	CO_2 emissions, per capita	A	A	A	A	A	A	A
	Land consumption for transport infrastructure (roads, parking, etc.)	A	A	A	NA	NA	NA	NA
	Per capita energy consumption, by fuel and mode	A	A	A	A	A	A	A
	Air and noise pollution exposure and health impacts	A	A	A	A	A	A	A
	Vehicle travel by mode (non motorized, automobile and public transport).	A	A	NA	NA	NA	NA	NA
	Land use density (people and jobs per unit of land area)	A	A	NA	NA	NA	NA	NA
Economic	Per capita congestion costs (Total time spent in traffic)	A	A	NA	NA	NA	NA	NA
	Total transport expenditures (vehicles, parking, roads and transit services).	A	A	NA	NA	NA	NA	NA
	Household expenditure allocated to transport (% budget)	A	A	NA	NA	NA	NA	NA
	Expenditures on transportation for local government (annual, per GDP)	A	A	NA	NA	NA	NA	NA
	Transparency of costs and investments	A	A	NA	NA	NA	NA	NA
	Harmful subsidies and green fiscal policies	A	A	NA	NA	NA	NA	NA
Social	Transport system diversity/transportation variety	A	A	NA	NA	NA	NA	NA
	Quality of transport for disadvantaged people (disabled, low incomes, children, non-driver, etc.)	A	A	NA	NA	NA	NA	NA
	Access to public transport (population served by public transit near around a train station, subway, bus stop)	A	A	NA	NA	NA	NA	NA
	Fatality and injured of traffic accidents per capita or person/km	A	A	NA	NA	NA	NA	NA
	Satisfaction of citizens and variety and quality of transport options (walking, cycling, ridesharing and public transport).	A	A	NA	NA	NA	NA	NA
	Safety	A	A	NA	NA	NA	NA	NA
	Health	A	A	A	A	A	A	A
	Gender equality/equity between societies and groups	A	A	NA	NA	NA	NA	NA

Source : Santos and Riberio (2013)

The PAM identifies sustainability impacts resulting from system processes, characterising the issues (consequences) arising from these impacts with indicators. It is transparent and systematic, and helps the user to create an indicator set which is comprehensive, whilst avoiding double-counting. Particular issues can be further described with sub-indicators as mention in Table 3 which shows indicators as environment only .

Table 3 : Environmental indicators of car transport system sustainability

Input/output	Impact	Issue	EIR	Indicator	Metric
Energy	Acidification	Increasing acidity in soil, lakes and rivers	Communities	Emissions of pollutants characterized in Guinée et al. (2002)	t yr^{-1} SO_2 equivalent
	Eutrophication	Ecosystem degradation	Communities	See above	t yr^{-1} PO_4 equivalent
	Global Warming	Stores heat, causing global warming	Future communities	See above	t yr^{-1} CO_2 equivalent
	Photochemical Oxidation	Ozone causes irritation to respiratory systems and can damage vegetation and materials	Communities	See above	t yr^{-1} ethylene equivalent
	Ozone Layer Depletion	Depletion of stratospheric ozone causes greater incidence of UV	Communities	See above	t yr^{-1} CFC-11 equivalent
	Ecotoxicity	Freshwater toxicity, marine toxicity, terrestrial toxicity from emissions to air	Communities	See above	t yr^{-1}. 1,4-DCB equivalent
	Particulates	Degrades materials	Communities	PM10	t yr^{-1}
	Primary energy resource depletion[a]	Fewer available resources to meet future needs	Future communities	Total non- renewable energy consumed	GJ yr^{-1}
Material use	Waste to landfill	Use of land for waste disposal, emissions	Communities	Total waste	t yr^{-1}
	Abiotic resource depletion[a]	Use of non-renewable, non-recyclable and non-reusable materials leave fewer resources available to meet future needs	Future communities	Net materials lost	t yr^{-1} Antimony equivalent
	Material processing and extraction	Release of polluting substances	Communities	Heavy metals, toxic chemicals, solvents released	t yr^{-1}
Water	Contamination of water during vehicle lifecycle	Treating water involves an energy cost, dirty water can spread contaminants and bacteria	Communities	Quantity of water used	Litres

[a] Includes renewable resources used at an unsustainable rate.

(Source : Smith et al.,2013)

Table 4 shows indicators as economic only if they describe issues affecting the economic sustainability of the system itself. These indicators are presented in Table 4. The human/social indicator set (Table 5) comprises a crucial part of the sustainability analysis, because it includes indicators for the major benefit of car transportation to society – the provision of mobility as a service.

Table 4 : Economic indicators of car transport system sustainability

Input/ output	Impact	Issue	EIR	Indicator
Workforce	Value is added through the use of workforce	Generates profit	Capital Providers	Value added by automotive industry
Mobility	Accidents/casualties	Financial cost of accidents to society	Communities	Cost of physical damage, medical costs, emergency services
	Mobility is used to support economic activity	Speed of mobility – time is saved relative to other modes	Users	Value of time saved per km
	Additional revenue collected by the government as a result of car fleet operation	Government collects tax revenue to pay for public services	Communities	Fuel duty and Vehicle Excise Duty Collected
Energy	Air pollution	Hazardous to human health	Communities	Cost to health services of treatment
Material use	Release of hazardous materials	Hazardous to human health	Communities	Cost to health services of treatment

(Source: Smith et al.,2013)

Table 6 shows the average employment during each year, as well as the costs (to businesses) per employee, which cover gross wages and salaries (including redundancy and severance payments) and social security costs.

Table 5 : Human/social indicators of car transport system sustainability

Input/ output	Impact	Issue	EIR	Indicator	Metric
Workforce	Employment	People can support themselves	Employees	Jobs provided	Number of people employed
Energy	Air pollution	Hazardous to health	Communities	Fatalities induced by car-related air pollution	Number of deaths brought forward per year
				Morbidity induced by car-related air pollution	Number of hospital admissions per year
Mobility	Mobility is provided	People are able to travel	Users	Mobility provided by car fleet	Passenger-km per year
	Service quality	People are able to perform trips under certain conditions	Users	User service quality indicators (see Section 3.3)	Various
		The mobility needs of the community are met	Communities	Equality of modal opportunity indicators (see Section 3.3)	Various
	Noise	Hazardous to health	Communities	Morbidity related to noise	Number of medical interventions per year
	Accidents/ injuries	Resulting injury	Communities	Casualties resulting from road traffic collisions	Number of killed or seriously injured per year

Table 6 : Employment in the UK automotive industry . Cost in £(2005)

Sector	1995		2005		Change (%)	
	Employment (thousands)	Costs (£)/employee	Employment (thousands)	Costs (£)/employee	Employment	Costs/ employee
Manufacturing	282[a]	25,954	205	31,617	27.3	21.8
Sales (vehicles, parts, fuel) and maintenance	562[a]	11,965	560	17,383	−0.4	45.3
Total	843[a]	16,640	765	21,195	−9.3	27.4

Whitmarsh (2012) introduced Multi-Level Perspective (MLP) as an analytical tool for identifying and engaging with diverse stakeholder groups, including mainstream (‘regime’) and alternative (‘niche’) organisations. The MLP can be improved by integrating natural, behavioural and political science insights, and particularly by elucidating how behavioural–institutional change might occur. This is critical for transport research given the expressed and observed public resistance to changing travel behaviour. There is considerable scope to integrate natural, behavioural and political science insights to expand and improve the MLP to elucidate how behavioural–institutional change might occur. This is particularly critical for transport research given the expressed and observed public resistance to changing travel behaviour.

Cascetta et al., (2013) suggested Public Engagement (PE) PE in planning and designing transportation systems, describing its interactions with other more formal phases of decision-making and some of the tools that can be used for the various levels On the other hand PE does not make full use of the potential of quantitative methods developed over the decades for the design and evaluation of transportation projects.

Sustainability indicators have been used in road transport, urban transport, cities and vehicle growth and planning by different researcher. Different approach, indicators, purpose and reason for using such indicator are discussed as above. It is expected that decision maker can consider such approach to preserve the future generation requirement and need while developing current infrastructures.

Conclusion

As interest in sustainability grows, more agencies will begin to incorporate the concept in planning. While there are several initiatives in this area in developed countries, where few regional agencies have developed planning tools that successfully incorporate the comprehensive concept of sustainability (transportation system effectiveness, economic, environmental, and social aspects of sustainability) in the development of long-range plans, transportation improvement programs, and project selection. The main intent is to present this paper to show emerging guidance on the critical elements of sustainability evaluation—both from the view point of indicator frameworks and analytical models, and to demonstrate how a broad range of performance measures can be used effectively in sustainability evaluation within a multi criteria framework – to assess tradeoffs and identify dominant alternatives when considering competing alternative plans for transport, vehicle in sustainable scenario. The indicator set is thus likely to be widely applicable and is also manageable in size both are important criteria for adoption by transport and sustainability practitioners for other developing country also.

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