Seminar COST 356 EST "*Towards the definition of a measurable environmentally sustainable transport*",
20 February 2008, Oslo, Norway

Chains of causalities of environmental impacts

Robert Joumard[1], Santiago Mancebo Quintana[2], Gerassimos Arapis[3] & Tomasz Zacharz[4]

[1] Inrets, France, joumard@inrets.fr
[2] Univ. Politécnica de Madrid, Spain
[3] Agricultural Univ. of Athens, Greece
[4] Komag, Poland

Abstract

In order to prepare an encompassing ex-ante assessment of the impacts of the transport system on the environment by building impact indicators, the pressure-state-impact concept is widen into the concept of chain of causalities or process. A process is defined by an output of the transport system, a homogeneous series of physical, chemical, biological, psychological relationships between elements, and a final target. All the known today impacts of the transport system on the environment are described as a list of 43 chains of causalities. The knowledge of the relationships will be used to design indicators or to know what does and not does measure a given indicator.

Key-words: environmental impact, classification, process, chain of causalities, transport.

1. Introduction

To build tools for assessing the impacts on the environment of a transport system or sub-system asks for a definition of the impacts on the environment, defined by final targets and modifications of target. For instance, the final targets of the traffic safety are mainly the humans with death and injuries. To assess each impact, the best way should be to measure the impact itself, by counting or evaluating for instance the number of people injured or dead because the traffic system. But such counting can't be made only *ex-post* and does not give any indication on the causes of the impact, because the impact cannot be linked by a one-to-one relationship with the accidents: the accidents are not the only causality of human death and injuries: local air pollution, greenhouse effect, hazards, among others cause death and injuries. The account of death and injuries due to the accident needs to take into account the process of accident. It is especially easy in the field of traffic safety, much more complex for most of the impacts.

For an evaluation *ex-ante* or for looking for the causes of an *ex-post* evaluation, a clear and precise relationship has to be established with the transport system. Each process, each chain of causalities from the source to each final impact on the environment has to be described in detail: in terms of sources, intermediate and final targets, mechanisms between intermediate sources and intermediate targets. Such description allows us also to express clearly what a potential indicator measures and does not measure, and on which scientific mechanisms an indicator should be based. For instance the global warming potential evaluates the global temperature increase and not really the final impacts of greenhouse effect as sea level increase, the amount of fauna, flora and human habitat destruction, the food chain changes... The knowledge of the physical mechanism of the climate and temperature modifications as a function of greenhouse gas emissions allows to build the shape of the indicator 'global warming potential'.

At the same time, the description of the chains of causalities allows us to define quite precisely the term 'environment': What are the impacts on the environment? What are their characteristics or typical features?

The most common presentation of the environment, especially by economists, considers it as a resource used by the humans for producing economic goods. This resource is an ecosystem, i.e. the association between a physicochemical and abiotic (the biotope) environment and a living community characteristic of the latter (the biocenosis), including fossil resources. This resource is destroyed but can be renewed at a given extend: the environmental issue is a question of resource flow and capacity of the biosphere to support the effects of the human activities (carrying capacity): It calls the 7th principle of the Rio declaration (UNCED, 1992): "*...to conserve, protect and restore [...] the integrity of the Earth's ecosystem [...] the pressures their societies place on the global environment*". The pressure-state-impact (PSI) system from OECD seems well applicable to this meaning with a pressure representing a flow.

In parallel, the environment is often understood as the quality of our physical environment or the quality of life: a calm area with pure air and pure water, a beautiful landscape... It calls the first principle of the Rio declaration: "*Human beings [...] are entitled to a healthy and productive life in harmony with nature*". It is here often difficult to consider only flows or pressures.

These both meanings of the environment correspond roughly to the external and internal territory sustainability by Wackernagel and Rees (1999): the internal sustainability consists in protecting its direct environment and living area, but the external sustainability consists in protecting the world.

According to USEPA (1996)	OECD (2002)	COST 350 (2002)	Goger (2006), Goger & Joumard (2007)	Joumard & Nicolas (2007)	Corresponding chain in Table 4
All impacts from transport	All impacts from transport	All impacts from transport (red: global; black: local/regional)	Impacts from transport due to pollutant emissions (grey: out of the scope)	All impacts from transport (red: irreversible; black: reversible)	
	use of natural resources	non-renewable energy consumpt.		non-renewable resource use, including energy	21
		use of material resources			
pollutant emissions	climate change	climate change	Greenhouse effect	greenhouse effect	42
		ozone depletion	Ozone depletion		15, 16
	air quality	air pollution	Direct restricted health effects	local air quality	4
			Direct ecotoxicity		3
			Photochemical pollution	regional air quality (smog)	17, 18, 19, 20
	water quality	water pollution	Eutrophication	water quality / uses and régime	5
highway and airport runoff					24, 25, 26
toxic release					
sewage dumping					
					8
release of deicing compounds		soil pollution			24, 25, 26
waste		waste production			23
direct waste from vehicles					34

					41
noise	noise	noise nuisance/vibration		light and noise nuisances	29, 30, 31
					14
		traffic accidents		traffic safety	22
roadkill, wildlife collisions					35
Habitat disruption and land take by infrastructure	severance	barrier effects / land fragmentation		landuse	6, 7
		land uptake			9, 11
		soil erosion			
		hydrologic/hydraulic risks			27
			Sensitive pollution		37
	visual impacts			visual qualities of landscape/townscape	38, 39
	historical / archaeological / nature conservation	landscape / visual effects / aesthetics / cultural heritage			40
			Degradation of common man-made heritage	man-made heritage	2, 12, 27
			Degradation of historic man-made heritage		12
				biodiversity and protected areas	9, 10, 13
	loss of biodiversity		(Direct ecotoxicity)		
	acidification		Acidification		1, 2
				technological and natural hazards	
hazardeous material incident					28
introduction of non-native species					32
habitat disruption by wakes / anchors					33
					36
					43

Table 1: Correspondence between the environmental impacts as listed by 5 references, and the list of processes proposed in this paper.

2. Precise list of environmental impacts

Such definitions are much too global and rough to be useful for describing the environmental issue or the impact on the environment of a human activity as the transport system, and for designing environmental impact indicators. An exhaustive list of the chains of causalities is necessary to present a full picture. But the definition of the environmental or ecological impacts is neither clear nor precise in the literature. When lists of environmental impacts are given, they are often heterogeneous, merging impacts and sources: See some examples Table 1. For instance USEPA (1996) lists mainly the pressures or the first consequences of the transport system on the environment rather than environmental impacts (although designed as impacts). The use of natural resources, the hydrologic and hydraulic risks, the traffic safety and the final impacts as sensitive pollution are missing; A contrario rarely mentioned impacts are listed as introduction of non-native species, habitat disruption by wakes or anchors, direct waste from vehicles, roadkill and wildlife collisions. The other references examined merge impacts on the environment as climate change or visual effects, and intermediate states of the environment as local air quality, water quality. Goger (2006) and Goger & Joumard (2007) give the most precise list but only due to atmospheric pollutant emissions: In this field, impacts are distinguished when they are due to different chains of causalities, taking into account the fact that, as stated in Wäger (2006), the impact categories shall together enable an encompassing assessment of relevant impacts, which are known today (completeness), but at the same time should have the least overlap as possible (independence).

3. The concept of chain of causalities

It is the reason why we prefer to enlarge the PSI picture to the concept of process or chain of causalities between a cause and a final impact, with possibly a succession of couples cause-impact. A good example is the greenhouse effect with the greenhouse gases (GHG) as a first cause, which by physical phenomenon increases the earth temperature, which modifies the global and local climates, with impacts on the agriculture, sea level, with impacts on all the biocenosis including the humans. If an initial pressure can be easily detected (GHG emissions), they are afterwards a lot of intermediate states and impacts. Another advantage of the concept of process or chain of causalities is to be much wider than a physical flow problem: any process can be taken into account, as cultural, psychological, psycho-physical, or biological effect.

A chain of causalities can be described through:

- The element(s) of the transport system, which is at the begin of the process, taking into account the life cycle approach, ie. considering all the activities involved. 3 main subsystems are involved (infrastructure, fuel, and vehicle), and for each of them 5 types of activities (production, existence, use, maintenance, and destruction). All together there are 13 subsystems-activities: See Table 2. The 13 subsystems can be simplified into 4, as coloured in Table 2 and used in Table 4, by considering the 3 main subsystems but extracting the traffic, i.e. the use of the infrastructure, final energy and vehicle.

<table>
<tr><td rowspan="4">Infra-structure</td><td>building (1)</td><td rowspan="4">Energy</td><td>final electricity production (5)</td><td rowspan="4">Vehicle</td><td>production (9)</td></tr>
<tr><td>existence (2)</td><td>electricity distribution (6)</td><td>existence (10)</td></tr>
<tr><td>maintenance (3)</td><td>fuel production (7)</td><td>maintenance (11)</td></tr>
<tr><td>destruction (4)</td><td>fuel distribution (8)</td><td>destruction (12)</td></tr>
<tr><td colspan="6">Traffic = infrastructure - final energy - vehicle use (13)</td></tr>
</table>

Table 2: Typology of the main transport subsystems involved in the environmental impacts. Colours correspond to wider subsystems as used in Table 4.

- The final targets: Goger (2006) and Goger & Joumard (2007) consider 3 targets (nature, humans, man-made heritage) and a pseudo-target, the earth. In addition the Eco-indicator approach (Brand et al., 1998; Goedkoop & Spriemsma, 2000) includes three types of endpoint damages: resources, ecosystem quality, and human health. The 2 first are subdivisions of the target nature. The (human) health is defined by World Health Organisation (WHO, 1946) as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*". Therefore it is useful to distinguish health in a restricted meaning (absence of disease or infirmity) and the complement so-called human well-being, because the processes are often very different. Finally we get the target structure presented Table 3.

<table>
<tr><th colspan="2">Targets</th><th>Pseudo-target</th></tr>
<tr><td rowspan="2">Nature</td><td>Resources</td><td rowspan="5">Earth:
Covers all the targets: the three previous targets (ecosystems, humans and man made heritage) and physical environments such as the atmosphere and the oceans</td></tr>
<tr><td>Ecosystems:
Nature understood as ecosystems, i.e. the association between a physicochemical and abiotic (the biotope) environment and a living community characteristic of the latter (the biocenosis)</td></tr>
<tr><td rowspan="2">Humans:
Humankind which we extract from nature and focus on its health as defined by the WHO</td><td>Human health:
In a restricted meaning</td></tr>
<tr><td>Human well-being</td></tr>
<tr><td colspan="2">Man-made heritage:
With a distinction is made between common and historic buildings</td></tr>
</table>

Table 3: Structure of the targets of the impacts on the environment.

- The in-between elements, i.e. the chain of causalities between the transport system and the final targets, to be described in detail. To design impact indicators, it is important to know the scientific milieu able to understand the process, and therefore to give the scientific disciplines involved. We propose a first and simple science structure: physics, chemistry, biology, psychology/sociology. It is important also to know if the process is linear or not, and if the transport system characteristics are major or minor explanation parameters, in order to know how these characteristics can be used for indicator building. Finally the reversibility is a major parameter from the sustainability point of view; The distance and time scales indicate who is concerned, if it is a local/global, shot/medium/long term impact.

It disaggregates the different impacts found in the literature in order to understand the complexity of the processes involved, to identify the related sciences and to estimate the order of magnitude of the impact in space and time.

4. Typology of chains of causalities

According to this structure, a typology of the chains of causalities of the environmental impacts of the transport system is proposed Table 4. 29 chains are distinguished, and 43 when taking into account differentiation in the last steps of the process corresponding to different final targets. The chains are independent and encompass all the relevant impacts found in the literature.

The description of the chains could be more detailed, by dividing a chain into two or more chains, if it is considered as not homogeneous in terms of process or targets. In addition some chains can be missing.

A contrario, the aggregation of impacts is possible when the knowledge necessary to build impact indicators is similar and if the main characteristics of the chain are similar. As, to be practical, the number of categories should amount to a not too high number, and considering the importance of each impact and the availability of indicators, some impacts could be merged, or minor chains be deleted. Because it is important to give the possibility to further users to perform such simplifications, the chain structure has to be as detailed as possible: It is easier to merge and delete than to add processes.

Sources										Target					
Iinfrastructure	Energy	Vehicle	Traffic	First step of the chain (pressure)	**Identification**	reversibility, distance and time scale from the source	Chain of causalities (states and processes) and *final impact* (main scientific disciplines involved: P: Physics; C: Chemistry: B: Biology; PS: Psychology / Sociology)		N	Resource	Ecosystem	Health	Human well-being	Man-made heritage	Earth
	*	*	***	Emissions NOx, SO_2	**Acidification**	Mm, year	*(incl. secondary effect of photochemical pollution)* Dispersion in the atmosphere (P), possibly wet and dry deposition, chemical reaction (C) and therefore formation of acid compounds,	dispersion in air, water and soil (P), ecotoxicity on fauna and flora (B). *Decrease of ecosystem health, loss of biodiversity.*	1		ES				
								deposition on surfaces (P), chemical reactions with materials (C). *Loss of man-made heritage* (PS), *destruction of archaeological, classical or historic remains* (P), *loss of cultural legacy* (PS).	2					M	
	*	*	***	Emission of particles and air pollutants	**Direct toxicity**	km, day	Dispersion in the atmosphere and water (P), sometimes dispersion in food (P),	*direct ecotoxicity on fauna and flora* (B).	3		ES				
								direct restricted health effects (B).	4			H			
	*		***	Emissions NOx	**Eutrophication**	10 km, year	Dispersion in the atmosphere and water (P), increase of plant biomass (B), *anoxia of fauna and flora* (B).		5		ES				
***			*	Land take	**Habitat fragmentation**	practically irreversible, km, year	Cutting of the fauna habitat (B). *Loss of ecosystem health, loss of biodiversity.*		6		ES				
							Cutting of the human habitat, *reduction of living areas of people* (B, PS)		7				HWB		
***				Land take	**Hydraulic changes**	km, year	Hydraulic changes, *modification of fauna, mainly, and flora habitat* (P, B).		8		ES				

* * *	*	*		Land take by infrastructure building	**Land take**	practically irreversible, km, year	Waterproofing of areas, *decrease of ecosystems (P, B). Loss of biodiversity.*		9	R ?	E S				
							Waterproofing of areas, *loss of natural and wildlife protected areas.*		10		E S				
							Waterproofing of areas, loss of available land for humans, *modification of outdoor recreation areas* (PS).		11				H W B		
							Destruction of archaeological, classical or historic remains (P), *loss of cultural legacy* (PS).		12					M	
	* *			Agriculture for biofuels	**Biofuel agriculture**	km, year	Transformation of natural areas, *disappearance of fauna and flora* (B).		13	R ?	E S				
* *			* *	Emission of light	**Light pollution**	Mm, min	Modification of the luminosity of the open space (P), modification of the biota behaviour (B), *effects on biota health*.		14		E S				
			*	Emission of halogen compounds	**Ozone depletion**	earth, year	Dispersion in the atmosphere (P), chemical reaction (C) depletion of ozone layer, increase of UV on the earth (P),	*ecotoxicity on fauna and flora* (B).	15		E S				
								health effects (B).	16			H			
	*	*	* * *	Emission of NOx, NMVOC, CO.	**Photochemical pollution**	Mm, day	Dispersion in the atmosphere (P), chemical reaction (C) and therefore increase of photochemical pollutants as ozone,	*health effects* (B).	17			H			
								loss of agriculture productivity (B).	18	R					
								ecotoxicity on fauna and flora (B).	19		E S				
								deposition on surfaces (P), chemical reactions with materials (C), loss of man-made heritage (PS), destruction of archaeological, classical or historic remains (P), *loss of cultural legacy* (PS).	20					M	
								Secondary effects: - greenhouse gas (*see greenhouse effect*) - acidification (*see acidification*)	-		(E S)			(M)	
*	*	*	* *	Non-renewable	**Non-renewable**	irreversible, Mm, 100	*Decrease of metals, fossil fuels availability for the future* (P).		21	R					

			*	resource use	**resource use**	years									
			* * *	Accidents	**Traffic Safety**	partially irreversible , m, -	*Human death, injuries* (B).		22			H			
* *	*	* *		Waste disposal	**Non-recyclable waste**	Partially irrevers. (nuclear waste), all	Includes the nuclear waste. Dissemination in the nature (P), *impacts on health and ecosystems* (B).		23		E S	H H	H W B		
*			*	Emission of gazeous, liquid or solid pollutants	**Soil and water pollution**	100 km, year	Dispersion in the soil and water (P),	*ecosystem health* (B).	24		E S				
								health effects (B).	25			H			
								recreational areas forbidden (PS).	26				H W B		
* * *				Risk of floods	**Hydraulic risk**	km, year	*Destruction of natural and human habitat* (P).		27		E S	H		M	
	* *		* *	Risk for industrial safety	**Technological hazards**	km to earth, day to century	Industrial accidents, included of nuclear power plants. Dispersion in the atmosphere, soil and water (P), *biological impacts on humans and biota* (B).		28		E S	H H			
* *			* * *	Emission of noise	**Noise**	km, hour	Diffusion (P), *disappearance of calm areas* (PS).		29				H W B		
							Diffusion in air, absorption or reflection by surfaces (P), *annoyance for people* (PS), *health effects* (B).		30			H	H W B		
							Diffusion in air, absorption or reflection by surfaces (P), *ecosystem health* (B).		31		E S				
			* *	Introduction of non-native species	**Introduction of non-native species**	Earth, irreversible	Small individuals, seeds… disperse and survive (B), modification of biocenosis. *Loss of biodiversity*.		32		E S				
			*	Emission of wakes	**Habitat disruption**	km	Microhabitat changes. *Loss of biodiversity, loss of ecosystem health.*		33		E S				

					by wakes / anchors									
			*	Emission of waste	**Direct waste from vehicles**	100 m, year	Waste thrown directly from the vehicles, accumulation. *Annoyance* (PS), especially if the landscape is of high quality.	34				H W B		
			* *	Biota collision	**Biota collision**	partially irreversible , m, -	Fauna collision from small insects to big mammals or fish, damage by anchors. *Loss of biodiversity* (B).	35		E S				
			*	Risk of fire	**Fire risk**	10 km, year	Fire ignition by sparks, matches… or accidents. *Destruction of natural and human habitat* (P).	36		E S	H	H W B		
	* *		* * *	Emission of VOC	**Odours**	100 m, hour	Dispersion in the atmosphere (P) at short distance, *sensitive pollution perceived by smell* (PS).	37				H W B		
	*		* *	Emission of PM	**Soiling**	100 m, year	Dispersion in the atmosphere (P) at short distance, deposition on surfaces (P), chemical reactions with materials (C), *sensitive pollution perceived by the sight* (PS).	38				H W B		
	*		* *	Emission of PM and atmospheric pollutants	**Visibility**	100 m, day	Dispersion in the atmosphere (P) at mid distance, chemical reaction in air (C), *sensitive pollution perceived* by the sight (PS).	39				H W B		
* * *				Land use	**Visual qualities of landscape/ townscape**	practically irreversible , km, year	Infrastructure presence, *annoyance* (PS), especially if the landscape is of high quality.	40				H W B		
			* *	Emission of vibration	**Vibration**	100 m, hour	Heavy traffic (HDV, trains) vibrations, mass diffusion, *destruction of earth houses* (P), *annoyance* (PS).	41				H W B	M	
*	*	*	* * *	Emission of air pollutants	**Greenhouse effect**	irreversible , earth, century	Dispersion in the atmosphere (P), sometimes chemical reaction (C) and therefore creation of secondary pollutants, increase of the greenhouse effect (P), climate change (P), sea level increase (P), *destruction or modification of habitat for fauna, flora and humans* (P), *change in food chain* (B), *economic losses* (PS)...	42						E

	* *	*	* * *	Emission of aerosols	**Dimming**	100 km and earth, day to month	Dispersion in the atmosphere (P), physical reactions (P) and sometimes chemical reactions (C), regional dimming, regional temperature decrease, global climate changes, *destruction or modification of habitat for fauna, flora and humans* (P), *change in food chain* (B), *economic losses* (PS)...	43						E

Table 4: Proposed list of the main chains of causalities of environmental impacts with some characteristics.

5. Conclusion

To describe the environmental impacts of an activity as transport through a complete list of independent chains of causalities allows us firstly to give a precise definition of the term 'environment'. In the literature, the differences in the impacts considered translate often the research area of the author, and, when the work is more global, the local perception of the environmental or ecological issue. For instance the loss of visibility above the cities, due to air pollution, is always cited in North America, but never in Europe, although the physical situations are similar. It is especially important to define the term environment, when today the environmental issue is taken into account by most of the transport specialists without precise knowledge of this field: In this case the environmental issue is very often reduced to greenhouse gases or to few well known impacts, or are reduced unconsciously to impacts for which simple to use assessment tools are available.

According to COST 356 (Joumard, 2008), *an indicator of environmentally sustainable transport is a variable, based on measurements, representing potential or actual impacts on the environment, or factors that may cause such impacts, due to transport systems, flows or policies, as accurately as possible and necessary.* The precise description of the environmental processes constitutes then a powerful tool for indicator assessment, similar to that done by USEPA (1996). *A priori*, it can be stated that the more to the right the indicator is, the more precise the final impact is. It is mainly a tool to define what precisely an indicator does represent: Does it represent the final impact, or an intermediate one? How accurately is the process translated into the indicator function? Which relevant impacts are not taken into account by existing indicators? Isn't it possible double counting?

When the aim is to design new indicators of environmentally sustainable transport, the knowledge of the process indicates which scientists should be asked about the best way to represent the impact. It is also a comprehensive basis to study the social perception of the environmental issue by survey, whom outputs can be used to balance the quality of local air, of regional air, noise, greenhouse effect… according to the focus placed on each of these impacts, as made for the Personal Security Index designed by the Canadian Council on Social Development: See Tsoukalas & MacKenzie, 2003).

References

Brand G., Braunschweig A., Scheidegger A. & Schwank O. (1998): Weighting in Ecobalances with the ecoscarcity method – Ecofactors 1997. BUWAL (SAFEL) Environment Series, No. 297, Bern. www.e2mc.com/BUWAL297%20english.pdf

COST 350 (2002): Integrated Assessment of Environmental Impact of Traffic and Transport Infrastructure, executive summary of final deliverable of Workin Group 1. 7 p. /www.rws.nl/rws/dww/home/cost350/

Goedkoop M. & Spriemsma R. (2000): *The Eco-Indicator 99: A damage oriented method for Life Cycle Impact Assessment.* Methodology report. 2nd Edition, 214 p. www.pre.nl/eco-indicator99/ei99-reports.htm

Goger T. (2006) : Un indicateur d'impact environnemental global des polluants atmosphériques émis par les transports. Thèse, Insa Lyon, 28 nov. 2006, et rapport Inrets, n°LTE 0633, Bron, France, 283 p.

Goger T. & Joumard R. (2007) : A method of building an aggregated indicator of air-pollution impacts. 3rd int. conf. *Sustainable development 2007*, 25-27 April 2007, Algarve, Portugal.

Joumard R. (2008): Definitions of indicator within the COST action 356 EST. Seminar COST 356 EST "*Towards the definition of a measurable environmentally sustainable transport*", 20 February 2008, Oslo, Norway.

Joumard R. & Nicolas J.P. (2007) : Méthodologie d'évaluation de projets de transport dans le cadre du développement durable. 12[e] coll. int. *Évaluation environnementale et transports : concepts, outils et méthodes*, 18-22 juin 2007, Genève, Suisse.

OECD (2002): *Impact of Transport Infrastructure Investment on Regional Development.* http://www.cemt.org/pub/pubpdf/JTRC/02RTRinvestE.pdf

Tsoukalas S. & MacKenzie A. (2003): Personal Security Index 2003: A reflection of how Canadians feel five years later.CCSD, Ottawa, 87 p. www.ccsd.ca/pubs/2003/psi/

UNCED (1992): Rio Declaration on Environment and Development. 3 p. www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163

USEPA (1996): Indicators of environmental impacts of transportation - Highway, Rail, aviation and maritime transport. USEPA report, 230-R-96-009, Washington, USA, 268 p.

Wackernagel M. & Rees W. (1999): *Notre empreinte écologique*, Ecosociété, Paris, 207 p.

Wäger P. (2006): Life Cycle Assessment – a short overview. COST356 WG1 meeting, Madrid, 18-19 October.

WHO (1946): Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.