Life Cycle Analysis and Decision Aiding: An example for roads evaluation.

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Abstract

Road infrastructure building in civil engineering implies high initial cost investments whereas environmental effects have extensively been considered : i) before the construction regarding infrastructure localisation inside a given territory ii) only taking into account possible impacts on territory during infrastructure exploitation. A more global approach of environmental impacts through the whole infrastructure life cycle would therefore be of great interest to give more complete evaluation for decision aiding. Among possible methods available for such an approach, Life Cycle Analysis (LCA) is a methodology considering together resources extraction and materials manufacturing, construction steps, exploitation and maintenance during life time of a manufactured product. Although LCA can be applied to road materials evaluation, the methodology has to be adapted for the full infrastructure because of different road layers service life cycles. Anyway, economic evaluation remains a valuable mean for choosing between several road variants.

Economical aspects coupled with an LCA environmental evaluation can threfore provide a relevant multicriteria approach to the decision-maker. However, before such methodology application, the use and place of LCA in a decision process should be defined without ambiguity.

Hence, this paper deals with similarities and differencies between LCA and what we call a Decision Aiding Process. Both processes are compared and analysed to determine how LCA can be used for taking decision.

Keywords

Decision Aiding Process, décision context, environmental evaluation, LCA, problem structuring, road evaluation, robustness analysis, uncertainties, validation.

Introduction :

New environmental expectations are expressed today more and more clearly by all of the socio-economic actors. These requests generate decisional problems which should consider not only traditional economic implications, but also an environmental dimension which makes them more difficult to approach.

There is a variety of approaches allowing, according to needs, to provide information on the environmental aspect of a product or to study its environmental impact and this, considering various scales [4].Nevertheless, recent studies carried out in road field refer and/or are based on LCA methodology. According to the LCA authors and studies presented, one notes that taking into account the life cycle appears partially: either regarding to the subsystems considered, the list of inventory retained, or concerning the source of data and the analysis of their quality [7].

In substance, it seems that the comparative character of the evaluations performed in the LCA framework leads to consider it as a decision aiding tool. The object of this article consists firstly in drawing attention of the LCA practitioners to the possible deviations of this method when it is used in a decision perspective. In the second time, it is a question of clearly specifying the role and the use which should be made of LCA in the framework of decision aiding process.

At these ends, this paper will initially briefly present the unfolding of the LCA carried out on the RN76 building site. Afterwards, the concepts of *LC*A and *Decision Aiding Process* will be pointed out to finally approach the articulation of both.

I- Unfolding report of the RN 76 LCA

The restoration of a portion of the *RN 76* road was used as experimental building site for the data collection relating to construction of a roadway at various recycling rates. This building site, true site of full-scale experimentation, aimed at collecting environmental data on the basis of specific measurements. The corresponding economic data have also been gathered. Life cycle assessment of a roadway among the four or five layers classically constituting the roadways starting from the deconstruction of the existing layer was the prime objective to be reached. The second objective, it was to evaluate the repair processes of the roadway layer studied by considering its deconstruction then its rebuilding with various rates of recycling (0%, 10%, 20% and 30%) of the old RN76 pavement. The technological process used for the manufacture of roadway materials for the four studied solutions of recycling was a fixed hot-mix plant using with rotary dryer mixer which heats materials up to 165°C approximately. This in situ data acquisition allows, within the framework of this article, to illustrate the ideas and remarks that will be presented on the LCA and decision making issue.

As prescribed in the LCA standard, the presentation will be done in several steps whereas it begins as follows:

I.1 Aim of the study

The RN 76 LCA assessment focused on:

- Identifying the best solution of recycling among those tested on the basis of the environmental impacts and the direct costs generated,
- Obtaining replies on the possibility of generalizing the results of this study to other building roadworks.

The LCA was selected as the framework of this environmental evaluation because it makes it possible to carry out a comparison of these various solutions on the basis of an environmental impacts family whose relevance and exhaustiveness are justified.

I.2 Studied functions

The functions to be compared are processes of rehabilitation of the binder course of a roadway using hot-mix asphalt containing different proportions of reclained asphalt pavement (RAP) obtained by milling of the road pavement.

These processes unfold according to the following phases:

- Deconstruction of pavement layers,
- New asphalt manufacturing to rebuild a new pavement at the roadway site,
- Rebuild the roadway.

The processes thus primarily differ by the RAP rate. Four rates were tested:

- **Rate 0%** the asphalt used for the roadway rebuilding does not contain recycled aggregates.
- **Rate 10%, 20%, 30%** the asphalt used for the roadway rebuilding contains 10% (Respectively 20% and 30%) of aggregates resulting from the milled old pavement.

The **Functional unit selected** corresponds to 95 tons of hot-mix asphalt, that is to say one hour of asphalt production processing. The course of the study, as well as the whole of the subsystems taken into account are presented in Fig.1.

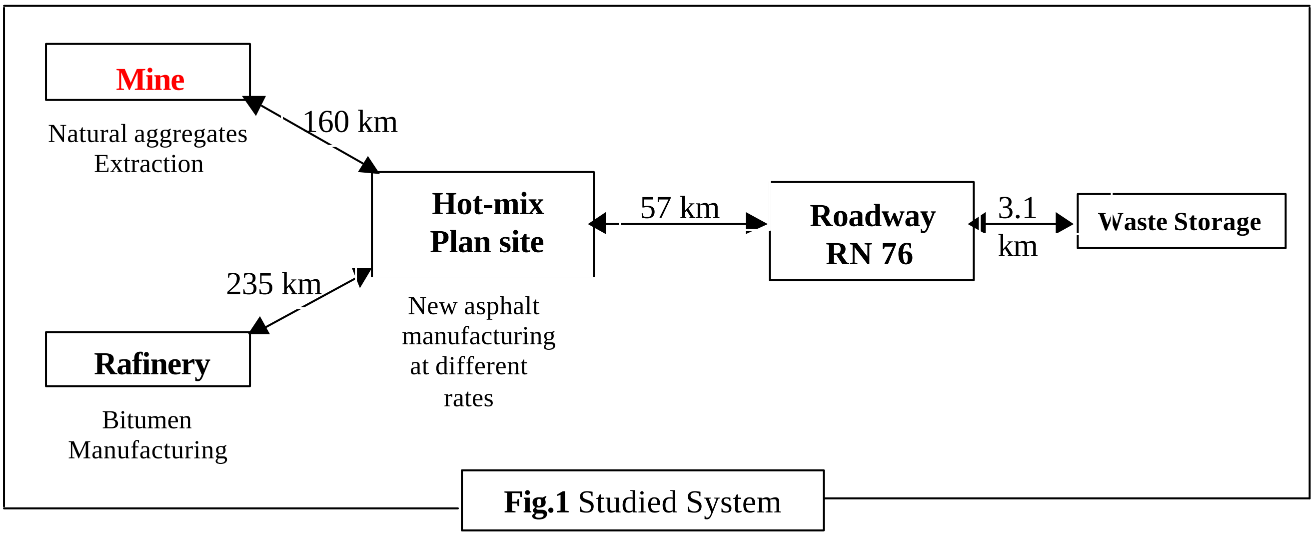

Fig.1 Studied System

For the fourth functions described, an environmental criteria family was proposed. In addition, an economic criterion, usually not taken into account according to the standard ISO 14042 but necessary to approach the decision-making concerning the rates of recycling to be chosen was also defined. Hence, the family of criteria thus defined remains still applicable to other similar studies.

II - LCA: Definition and Concepts

The LCA, such as defined in the standard ISO 14042, is a tool for evaluation of the potential impacts on the environment of a system including the whole activities associated with a product or a service, since the extraction of the raw materials until waste disposal. The LCA is applicable to any preparation or evaluation of a private or public decision under the angle of its impact on environment.[13].

The phases of the Life Cycle Analysis are defined according to the results that they produce as explained below.[13]

Phase I : Definition of the objectives ISO 14040

Requirements related to this stage are:

- The definition of the aims of the study,
- The choice of the function studied or of the functions to be compared (Produced, Services, Processes),
- The choice of the functional unit,
- The delimitation of the system boundaries (Physical, Geographical and temporal),
- The choice of the assumptions and formulation of the results (Rules of assignment, level of abstraction...).

Phase II : Life Cycle Inventory ISO 14041

In this phase, it is primarily a question of characterizing the physical phenomena and knowledge of processes involved both at the plan of the sources of impact and concerning the targets. Thus one proceeds to the:

- Construction of the framework of study,
- Data gathering
- Construction of a data-processing model
- Analysis and interpretation of results.

Phase III : Evaluation of the Potential Impacts ISO 14042

During this phase, one is interested in:

- The attribution of inventory data to the categories of impact (Classification); it is a question of *Defining* a relevant list of impact categories to be taken into account and of *Affecting* to it the inventory flows.
- Modelling the inventory data within the categories of impact (Characterization); the purpose here is to define the impact indicators which, will make it possible to quantify the specific contribution of each affected flow to the category of impact considered.
- Possible Aggregation of the results depending on the cases.

Phase IV : Interpretation of the results ISO 14043

This ultimate stage consists in establishing conclusions and recommendations with the decision-makers, in coherence with the fixed objectives.

Let's note that the above methodological framework allows a great flexibility, which can be expressed primarily in two points:

1- There is a very clear discrepancy between the formalization degree of the first two phases and the two last ones. Phases I and II, whose objectives are the collection and the structuring of the data necessary to the LCA are clearly and explicitly defined. Phases III and IV corresponding to the data exploitation and possibly to the décision making remain on the other hand badly defined, in particular, at the time of the impact characterization and the choice of an aggregation method. This established fact appeared very clearly at the time of the undertaken study (cf I) when this lack of a clear and defined method leads to define the family of impacts according to scientific uncertainties (Ignorance of becoming substances, of their effects, duration...) and to the aggregation procedure to be adopted.

2- The definition of the LCA applicability remains rather fuzzy. The terms "the LCA is applicable to any preparation or evaluation of a decision...." [13] includes both cases of a simple evaluation of the environmental impacts of a process or a product, and cases for which a decision must be made on the basis of result provided by LCA.

   There is a very clear difference between these two cases such that décision making requires a broader and more complex structure than a LCA. This structure is known as a Decision Aiding Process (DAP).

III Decision Aiding Process

III.1 Definitions and Concepts

Decision aid is defined as the activity of whose takes support on clearly clarified models but not necessarily completely formalized, aids to obtain brief replies to the questions posed by a speaker in a décision making process, such elements contribute to clarify the decision and normally to recommend or simply to support a behaviour likely to increase coherence between the evolution of the process on the one hand, objectives of the system of values to the service of which this speaker is placed on the other hand. [10]

Decision Process is a sequence of interactions amongst persons and/or organisations characterising one ore more objects or concerns.[1]

Actors are the participants in a decision process.[1]

Client(s) is an actor in a decision process who asks for a support in order to define this behaviour in the process. [1]

Analyst is an actor in a decision process who supports a client in a specific demand.[1]

Decision aiding process is a part of the decision process, and more precisely the interactions occurring at least between the client and the analyst.

This interaction will be the object of attention in what follows.

Literature focused on decision aiding processes is rich and complex; we will use in what follows the definition of the stages of such a process as suggested by TSOUKIAS [12].This definition adopts an operational approach, each stage being able to be characterized by the results that it generates.

III.2 Décision aiding process steps

Step 1 the problem situation

A representation of the problem situation aimed to surround all the aspects of the problem by defining the triplet :

$$P :< A, O, S>$$

A: is the set of participants to the decision process;

O: is the set of stakes each participant brings within the decision process;

S: is the set of resources the participants commit on their stakes and the other participants' stake

Step 2 the Problem formulation

The objective is to provide a clear and formal representation problem for the decision maker. The analyst by proposing one or more formulations influence very strongly the process, This is why this step is crucial. This representation is declined like a triplet:

$$\Gamma : < A, V, \Pi>$$

A**:** is the set of potential actions the client may undertake within the problem situation as represented in P;

V**:** is the set of points of view under which the potential actions are expected to observed, analysed, evaluated and compared including different scenarios for the future;

Π**:** A general presentation of the problem with perspectives of solution.

Step 3 the Evaluation Model

We proceed to the effective construction of a representative model of the real situation. On the basis of constraint defined at the time of the preceding stages, an approach of modelling (OR, artificial Intelligence, MCDA....) is adopted. The model must, according to the cases to include some or the whole of the following elements:

$$M: < A^*, D, E, G, U, R >$$

A*: a set of alternatives on which the model will apply;

D: a set of dimensions or attributes under which the elements of A are observed, measured, described …..

E: Is the set of scales associated to each element of D;

G: is a set of criteria under which each element of A* is evaluated in order to take in account the client's preferences;

U: The uncertainty structure associated to D or/and G;

R: An aggregation operator.

Step 4: Final Recommendations

Final recommendation is the translation of the model's results from the abstract and formal language to the current language of the client. Furthermore, the validation and the robustness of recommendations must be done.

III.3 Decision levels

Within any organization, decisions are taken on several levels. Three levels of concern in decision were identified by Ansoff and organized under the pyramidal mode (known as of pyramid of Antony) [8] as presented in Fig.2

These levels of decision are characterized as follows [8], [9]:

Strategical decisions

- High Level of uncertainty ;
- Important temporal and geographical scales ;
- fuzzy Problems, badly definite ;
- Use of qualitative data and subjective judgements ;
- Incite the various actors to an active participation ;
- Multiple and differentiated participation from the various actors ;
- No optimization search.

Tactical and Operational Decisions

- A reduced Number of alternatives;
- Reduced Uncertainty (relative to the strategic level but always existing);
- Participation of the actors well defined and identified;
- Search for optimization ;
- Use of quantitative information;
- Well defined Problems ;

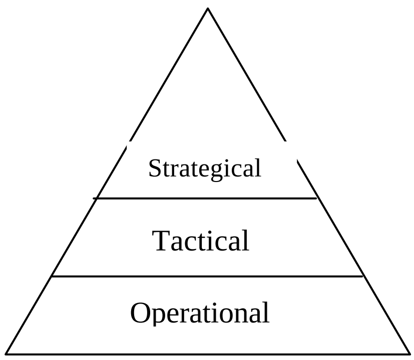

Fig2. ANTONY's Pyramid [9]

Referring to the characterization of decision levels suggested, the use of LCA appears hardly conceivable at a strategic level. Indeed, the bases of the modelling approaches used on this level (Approaches known as *Soft*) are radically different from those of LCA, because they are based on a permanent interaction with all the actors with an aim of using richness brought by their various visions (recognized as being completely subjective) of the problem which remain to be defined and structured.

The use of LCA for which information used is objective, rational and quantitative, interaction with actors reduced and the temporal and space scales defined, seems more adapted to tactical and operational contexts.

IV- LCA and Decision Aiding Process

Considering a structure for a decision aiding process, the question to be addressed is: Does LCA allow, through its own stages, to find all the results provided by a Decision Aiding Process (DAP)?

It seems that we should answer by the negative.

If we compare a DAP with an LCA, the latter would represent only steps 3 and 4 of the DAP. The LCA is in fact only a modelling approach taking in account all the flows relative to a product or a process, and where steps 1 and 2 (Problem Representation and Problem Formulation) of the DAP are not represented.

Actually, it is not possible to consider that the first stage of LCA (Definition of the objectives) is sufficient to provide the whole knowledge required to structure the studied problem. Hence, taking again the example of the RN76 study, important assumptions (Choice of the Functional unit, alternatives...), strongly conditioning the course of the process have been fixed without real scientific foundations. One of the results of the study was to precisely underline the interest of a new study undertaken on a different alternatives and another functional Unit .

This deficit of an upstream and necessary analysis limits strongly the success of all the process. Many of the criticisms towards LCA in the literature are, in our opinion, a direct consequence of this omission. Some of these criticisms are presented below:

- Using LCA, the definition of the impacts and criteria generates very complex and incomprehensible models for decision-makers. This exclusion of the actors other than the analyst can create an inadequacy between the request (expressed by the decision-maker) and the answer provided by the analyst. In fact, the phase of problem structuring allows to be sure that we are solving the right problem.

  Moreover, it is rather rare that the preferences of a decision maker are exclusively based on environmental considerations; the economic dimension (Place of the product on the market, costs, public perception...) must be taken into account. It is thus necessary for the analyst practising LCA to understand the importance of environmental dimension in the system of preferences of the client. It would not be necessary to carry out a complex and expensive LCA if the environmental aspects are not considered to be important at the time of the final décision making.

- The choice of LCA as a modelling approach must rise from an upstream analysis relating to:
  1- The benefit of choosing the LCA approach among other environmental approaches like SFA (Substance Flow Analysis), Impact Survey or a Risk Assessment. The factors of differentiation between these approaches are given by O.JALLIET and P.CRETTAZ [4].
  2- Since LCA is chosen as a modelling approach, the definition of the assumptions at the first phase, in particular the Functional Unit, the functions to be compared and the limits of the system strongly determines the success of the method as noted during the study undertaken (CF I) on the following points:
     - The choice of the Functional Unit (FU) was adequate for the environmental evaluation but inappropriate at the time of the costing because the increase in the costs was not proportional with the increase of FU. This inadequacy is caused by fixed costs which, for different FU, give different preference orders on the alternatives for the cost criterion.
     - The difference between the evaluated recycling rates should be, with the sight of the results, more significant to enrich the conclusions of the study; because it allows to identify clearly the differentiation factors for a better understanding of the advantages and drawbacks of each recycling rate. These facts prove that we should assign to the alternative choice phase as many efforts as to the flow measures and impact assessment.

- According to whether the LCA is addressed to decision makers having exclusively scientific interests (researchers.) or socio-economic stakes (Companies, local communities...), the LCA should not be carried out in the same manner. The difference should not only lie in the presentation of the results, it should exist, and in a more significant way, during the interaction with the decision-maker throughout the DAP.

Problems posed in a purely scientific framework are generally clear, structured and stripped of any ambiguity because based on a rational and scientific language. However for a company, the problem may be often badly defined, with fuzzy borders, and rather badly expressed needs, or sometimes even with needs to identify. Within this framework, the analyst should not lock up the problem in too complex models which would move away the decision maker from the DAP, preventing it from enriching his comprehension of the problem and thus, the identification of his true needs.

A second point which could be problematic is directly related to the methodological aspect of LCA. Actually, the LCA methodology, as described in the ISO standards [14], doesn't refer to very important notions in decision making which are *uncertainty*, *validation* and *Robustness of solutions.*

IV.1 Validation of the results

The validation of the results is an extremely important stage in a DAP. This one must as well relate to the results of the model as on the recommendations made later on the basis of those results. The LCA as described in the standards [14], does not specify any obligation of validation. Within the framework of LCA, the phase of validation should proceed as follows:

1- Generally, a complete LCA calls upon two models: A model of life cycle inventory and a model of impact assessment. For each one of those, the following phases must be carried out:

   Conceptual validation to check the relevance of choices, options and concepts used. In the case of the study, the adequacy between the assumptions made in the frame of the multicriteria approaches with the needs of the client was checked.

   Logical Validation to check the model structure. In the case of LCA, that would relate to the rules of assignment, the impact indicators...

   Experimental and Operational validation to check the accuracy of the model through its implementation on real data.

2- The validation of the recommendations must be done as well by the analyst who must make sure that its final model is correct as by the decision maker which must judge the adequacy of the model with its needs and confidence that he grants to these results.

IV.2 Robustness of solutions

This step consists on studying, up to what point, the provided conclusions resist to various factors of bad or insufficient knowledge being able to vary the initial data. In fact, these variations can have several sources: Uncertainty related to the measures performed, to the conditions under which the decision will be carried out or to the vagueness and evolutionary character of the client's preferences system.

In the LCA framework, the definition of geographical and temporal dimensions during phase 1 is already a first study of robustness of the solutions. Nevertheless, this is not sufficient. Many other factors can be considered, in particular economic factors (governmental policies, subsidies, evolution of the lawful framework...). Therefore, It would be judicious to specify, when developing recommendations, the need for identifying the whole variables likely to influence the relevance of the conclusions. This will not necessarily lead to a questioning of these recommendations, but will make it possible for the decision-maker to take into account, under a sufficiently broad and clarified framework, the whole contingencies and inherent conditions of the results.

Within the framework of RN76 building site, the study of robustness was related as well to the data uncertainties as to the possibility of vary the distances between subsystems (CF Fig.1) in order to determine the possibility of generalize the results to other building sites.

IV.3 Uncertainties

It is astonishing to see that generally in literature, all the results presented in LCA framework are usually not coupled with any uncertainties, although a very great number of assumptions are necessarily used at the beginning of LCA (Definition of the system boundaries, rules for assigning flows to the subsystems, scientific assumptions....).

The relevance of any DAP step is not conditioned by the need for leading to results directly and immediately usable, but by a sufficiently exhaustive and clear presentation of the necessary information to the decision-makers to mark out their inquiry field, or even, to widen it. Uncertainties, robustness and validation of recommendations are a very important part of this representation because it fixes the context where these recommendations are available.

In the LCA framework, two sources of uncertainties were identified:

IV.3.1 Data uncertainties

LCA being based on data measured under real conditions, it is necessary to take into account uncertainties related to measurements, equipment precision, data quality if they are extracted from other studies and process control in general.

IV.3.2 Endogenous Uncertainty

The second type of uncertainties is inherent to the method. Concluding a LCA requires setting many assumptions which strongly condition its unfolding, and thus, the quality of the results. These assumptions are:

1- **Posed by the analyst** In particular for phases 1 and 3 LCA. We can note some of them without being exhaustive: Choice of the studied functions, choice of the FU, delimitation of the system boundaries...

2- **Imposed by the method** Like any approach of modelling, LCA imposes restrictions to the analyst. This one must be conscious of that and take it in account during the DAP. We can note some of these restrictions:

- LCA supposes linearity between impacts and released quantities, without taking into account threshold effects, persistence, synergy.….
- LCA doesn't take into account geographical and temporal scales of emitted flows. Thus, two quantities, q_1 and q_2 of the same product emitted at two different places at different times will not have the same impact as a quantity $q_3 = q_1 + q_2$ emitted at the same time at the same place.

  LCA does not take into account such differences because the aggregation of flows is done without distinction of date or place. These restrictions make that the handling of data by LCA generates a "Loss of data quality" which should be identified but couldn't be removed.

  It thus appeared necessary to propose an approach to evaluate specific LCA uncertainty as defined above. This approach allows to evaluate impacts using intervals instead of specific values; intervals which will be used at the time of robustness study.

  The statement of the approach suggested will be the subject of a forthcoming publication.

V Conclusions

The above analysis derives from the study carried out on the RN 76 building site and set a certain number of limits for the use of LCA, limits aiming on the one hand to define its role in a DAP and on the other hand to present the minimal conditions for the success of the method.

LCA can be used simply as an environmental evaluation approach. Within this framework, it is not necessary to consider the whole concepts relating to decision clarified previously. On the other hand, if LCA is carried out in a decisional perspective, it is necessary to:

1- Consider LCA as one of the possible methods, which choice must be justified.

2- Integrate, in addition of the quantitative and objective information usually used for LCA, the whole of concepts and methods allowing for taking into account the actors subjectivity and preferences, and this, in a much more global framework of Decision Aiding process.

A non exhaustive presentation of these concepts and methods is explained as follows. Thinking of LCA upstream by a phase of Problem Structuring. Such a new stage aims to ensure the analyst he well understood the decision maker objectives, leading to a clear and shared problem formulation (between the analyst and the decision maker). Moreover, such stage should make possible to clarify the choices before beginning LCA first stage, in particular FU and system boundaries choice strongly conditioning the success of the LCA. The interaction with the decision maker must be realized during the problem structuring phase and the LCA first phase (definition of the objectives) in order to lead to an enough precise knowledge of the problem, and to make sure that those answers correspond to his requirements. Together with the LCA interpretation phase, an evaluation of uncertainty, validation of results and a study of robustness of solutions should be done, especially because a result is pertinent only in a given context the characteristics of which should be determined.

Finally to conclude, one has to notice that LCA is well adapted to the multicriteria analysis in the sense that the integration of socio-economical aspects can be carried out in a natural way, which offers the LCA an unquestionable advantage with respect to the other methods such as Environmental Impact survey and SFA.

All these remarks suggest to go on a research aiming at the reinforcement of this approach, in particular for uncertainties evaluation and problems structuring. Therefore, both LCA credibility and relevance of the environmental modeling approach would be increased.

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