THREE CHALLENGES, FOUR PITFALLS AND FIVE ACTIONS WHEN TEACHING CONCEPTUAL MODELLING

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Abstract

Modelling is of substantial use in policy analysis. Since policy analysis tries to facilitate decision making of complex multi-actor problems under uncertain circumstances, it needs to rationalize and simplify reality. This is the major challenge of doing policy analysis and especially modelling. The model as an abstract representation of the real system, should contain all (and preferably only) the relevant aspects of the real problem field. To acquire modelling skills requires lots of experience and training. We notice in our modelling courses that students have a distinct set of pitfalls when they try to model: abstraction pitfalls, labelling pitfalls, conceptual pitfalls, and analysis communication pitfalls. In this paper we give clear descriptions of each so that they are more easily recognisable. There are five recommended alternatives for which we provide concrete descriptions on how they are applied in practice. We labelled them as follows: (1) reiteration, (2) renaming or remaking, (3) keeping the big picture in mind, (4) returning to the roots, and (5) checking and double-checking. Our systematic way of describing the pitfalls, including the potential solutions, should make it easier for teachers and supervisors to guide junior modellers in building better models for multi-actor systems.

Keywords

Modelling, engineering education, working groups, multi actor systems, collaborative learning.

1. INTRODUCTION

Teaching engineering students how to think beyond optimal solutions is a challenge. This is one of our main tasks when teaching policy analysis methodology as part of the policy analysis curriculum for engineering students. Policy analysis methodology involves a structured approach to analyzing a complex reality (see [1]). The complex reality is of interest due to the presence of pathologies that constitute a wicked problem requiring developing solutions that encompass tradeoffs. Engineering students of the policy analysis program are taught the methodology, its steps, and the methods included in every step. The product/outcome of a policy analysis study is a set of policy measures that have the potential to deal and/or treat the problem.

One might think: Why modelling? Modelling is a key competence in engineering. In order to analyze or design systems we need to gain insight into specific aspects of the system. In order to achieve this, non-relevant elements and relations need to be eliminated. Modelling thus requires abstraction, a combination of reducing complexity of irrelevant aspects on the one hand and representing complexity of relevant aspects on the other [2]. The end result of a modelling exercise is, by definition, a less complex representation of the system or process that is being studied.

This is related to a modelling paradox experienced when teaching modelling. More specifically, it is observed that students tend to underestimate the effort required to acquire those modelling skills. Consequently, studying worked-out examples of a modelling task, or witnessing a teacher during a modelling effort, is insufficient to learn how to analyze and to model a system or a process. The abstraction skill is not visible to the students, and will be difficult to articulate for the teacher. Only when students are actively involved in the learning process through discussing the grammar of the language, the choices of demarcation, and the representation and consistency and completeness of the model, will they acquire the modelling skills [3].

Policy analysis methodology includes both a qualitative and a quantitative part (Appendix A). We need to specify here that we focus on the qualitative part of the policy analysis study and not on the quantitative part that includes different types of computational modelling (such as discrete modelling, continuous systems modelling and more). Conceptual modelling and its methods as the qualitative part of the policy analysis methodology is the core of our analysis.

To overcome the modelling paradox, we have introduced collaborative modelling workshops in the conceptual modelling course, in which students form groups and exercise with policy analysis methodology [3]. In this way, the active engagement of the students in the modelling process has proven to increase learning. However, we identified a number of pitfalls that students experienced over the course of the modelling exercise that required further attention. We realized that those pitfalls are related to the quality characteristics of a policy analysis study. We therefore provide a systematic presentation of the challenges linked to the quality characteristics of a policy analysis study (Section 2) and the common pitfalls of inexperienced analysts related to them (Section 3), as well as the ways we dealt with them during the workshops to aid students to overcome those pitfalls (Section 4). An overall discussion and concluding remarks are also included in the present paper (Section 5).

2. THREE CHALLENGES FOR THE QUALITY OF A POLICY ANALYSIS STUDY

The main goal of policy analysis educators is to teach students how to perform the analysis and how to self-evaluate and self-regulate their analysis so as to achieve a policy analysis study whose outcome is scientifically valid, of value, and of high content quality. These are three quality criteria for a policy analysis study that we consider as key competencies and comprise the three challenges for policy analysts.

Scientific validity translates into the reproducibility or replicability of the outcomes produced by the analysis from every analyst (see [4]). This means that the methods are applied correctly and any assumptions or simplifications made are openly presented and backed with arguments and reason. This concerns the first quality criterion for a policy analysis study.

For a policy analysis study to have **high quality content**, it needs to be consistent, comprehensive, and concise. ***Consistency*** relates to the link of the problem with the dimensions of the problem (subsystems) and with its context, and how this is reflected in the recommended alternatives. For checking whether the consistency attribute is satisfied, an analyst may ask: *how does this alternative relate to the problem under investigation/analysis?* ***Comprehensiveness*** relates to the breadth of the analysis when approaching the problem, and specifically to the set-up of the boundary of the system of analysis. An example here may clarify this quality attribute. Consider that the policy analysis problem that is being analyzed concerns unemployment in a developing country. An analysis of the problem that not only includes working conditions and salary scales but extends the problem to regions of unemployment, demographic conditions in the country, and expertise/level of education and specialization of productive population, can be considered as comprehensive. For checking whether this quality attribute is satisfied, an analyst may ask: *what are the dimensions of the problem*, or better*, what are the areas of influence and what are the possible sources related to the problem?* ***Conciseness*** relates to the demarcation of those dimensions/areas of the problem that are mostly influential and critical to the problem. In a complex reality, one may claim that everything relates directly or indirectly to everything. A policy analysis study escapes from such a complexity trap by indicating which areas of this complex reality are related to the problem. For checking whether the conciseness attribute is satisfied, an analyst may ask: *how does this area of impact/ area of analysis/ component of the system relate to the problem under investigation?*

Last but not least, the third quality criterion is the **value** of the analysis. The value of a policy analysis study relates to the applicability of the study, which means that it responds to a specified problem and that it includes alternatives that are assessed in showing the potential to cope with the problem (see also [1] p.16). It does not relate to the validity or content quality, but to the link of the analysis with the real world. For checking whether the value attribute is satisfied, an analyst may ask: *Who might be interested in the results of the analysis?*

These quality criteria can be linked to attributes (characteristics) that characterize a good policy analysis study (Table 1).

Table 1. Quality criteria and characteristics of a good policy analysis study.

Quality Criteria	Characteristics of a Good Policy Analysis Study
Scientific validity	Replicability/ Reproducibility
Content quality	Comprehensiveness
	Conciseness
	Consistency
Value	Applicability

3. FOUR PITFALLS TRIGERRING LEARNING IN CONCEPTUAL MODELLING

When teaching policy analysis to engineering students, we have recognized four different pitfalls related to the quality characteristics of a policy analysis study (Table 2). Every one of the pitfalls is seen to eliminate and/or relate to achieving quality in the analysis. It is noteworthy that we do not specify a pitfall for the validity criterion, since a student that hands in a non-valid study shows a complete failure in learning the methods and how they are applied. On the contrary, the four pitfalls that will be analyzed later in this paper relate to common pitfalls that policy analysis students make when applying the methods while maintaining the validity of the analysis.

In identifying those pitfalls, nine modelling intructors and educators were involved in action research and their experience as well as their insights on the nature of the pitfalls were communicated and incorporated in the pitfalls that are identified here. The basis of the discussion consisted of the insights and experience gained by teaching modelling in three different (master level) modeling courses (conceptual modeling course, continuous system modelling course and decision modeling course). In all these courses a combination of group work and individual exersices are realized and conceptual modelling is either the core or the first step in the modelling process.

Table 2. Quality criteria, characteristics of a good policy analysis study, and the pitfalls experienced when performing a policy analysis study.

Quality Criteria	Characteristics of a Good Policy Analysis Study	Pitfalls
Scientific validity	Replicability/ Reproducibility	
Content quality	Comprehensiveness	Abstraction pitfall
	Conciseness	Labelling pitfall
	Consistency	Conceptual chain pitfall
Value	Applicability	Analysis communication pitfall

This section will present the four pitfalls related to the quality characteristics of a policy analysis study concerning conceptual modelling in particular.

Abstraction pitfall

The abstraction pitfall relates to the comprehensiveness of the analysis. Theoretically, the students come up with a correct goal (see Figure 1 for an example of a goal hierarchy) or factor, but the level of abstraction is either too vague, too narrow, or too broad. This relates to the view of the system, and consequently of the problem. A blurry vision of the system produces a vague factor (e.g. ‘welfare of citizens’), a microscope vision produces too narrow a factor (e.g. ‘welfare of citizens younger than 20 years old’), and a spaceship vision produces too broad a factor (e.g. ‘global welfare’ or ‘EU welfare’). High abstraction levels can also cause a tunnel vision, group think or extreme focus. In such case,

important perspectives and policy alternatives can be disregarded and cast the eye only on one or a few policy options that threatens the comprehensiveness of the analysis. The desirable level of abstraction is the outcome of a helicopter view of the system/problem (e.g. 'natural capital (or welfare) of the Dutch citizens' when dealing with regional problems).

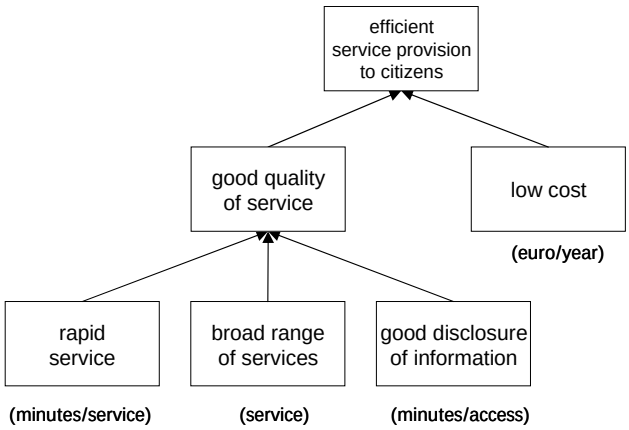

Figure 1. An example of a goal hierarchy.

When the level of abstraction is too vague, the conceptual modelling will not fit the actual problem.
We refer to abstraction pitfalls we have experienced when we teach/deal with the objectives tree method or goal hierarchy method of conceptual modelling. In a problem concerning tradeoffs between electricity generation and CO_2 emissions, students identify abstract goals such as 'welfare of citizens'. Such goals cannot be directly transformed into concrete, measurable, objective criteria. An example of an abstract factor is 'strictness of regulation'. Certainly a change in regulation will influence the choice for a potential solution. However, 'feeling' that this factor is necessary in your model does not mean it is suitable in its current form. No units can be attached to it, and there are no objective, non-discussable causal relations with other factors in this problem field. An example concerning the energy system in the Netherlands is given in Figure 2.

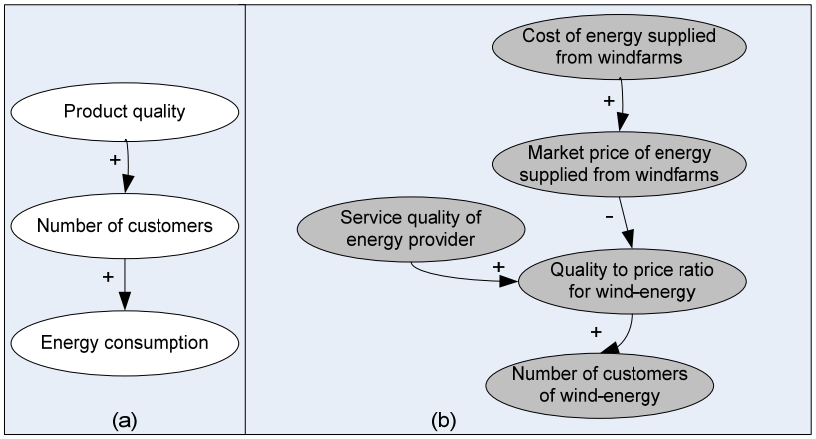

Figure 2. (a) An example of a causal relation diagram of inappropriate level of abstraction for the analysis of the energy system in the Netherlands in the face of energy shortages, and (b) the suggested causal relation diagram from the teachers (Source: epa1111 Student reports of Energy case, Autumn 2007).

When the level of abstraction is too narrow, the conceptual modelling does not facilitate decision making among different policy alternatives, since it focuses too much (directly or indirectly) on a subset of the potential set of solutions or, even worse, to one of them in particular.
If, in the earlier mentioned case about electricity generation, a goal like 'less nuclear waste' is specified, it is understandable in the light of the discussion in which also nuclear reactors are

considered to be a solution for the dilemma between generating capacity and CO_2 emissions. However, this goal most clearly points in the direction of one particular potential solution.

When the level of abstraction is too broad, the conceptual modelling shows the meta-level dimensions of the problem but does not contribute to a solution of the problem. In this case, the conceptual model represents "everything and thus nothing".
If you start with 'welfare' as a high-level goal, and you forget in the mean time the problem you are solving, you may end up with meta-level concepts like health, clean environment, employment, and safety. The problem that we have observed is that the step from these concepts to more consistently defined objectives (that reflect the dimensions of the problem under investigation) is too risky for un-practicthat ed analysts. A common phenomenon here is that students draw an objective hierarchy in which the relationships among the hierarchical levels is correct but the objectives (sub-goals) are too abstract.

Labelling pitfall

When dealing with policy analysis problems, there exist a large number of factors that contribute to the problem and that the analyst can include in the description/analysis of it [see also [5]]. However, it is observed –especially among policy analysis students – that there is an inconsistency between what students have in mind about a factor and how this factor is labelled.

When the label does not measure what the analyst means, the analysis is of no use to a decisionmaker, since it does not reduce the discussion about the decision, but increases it.
In a problem concerning tradeoffs between electricity generation and CO_2 emissions, students include factors such as 'emissions of CO_2', but when they indicate units, they use [µg CO_2 / m^3]. That reveals an inconsistency between what the factor is named (that is, what the student has in mind) and what it represents for the system (which is clearly a concentration). A straightforward check if the units fit the factor will overcome this pitfall.

In causal diagram modelling, the relationships will immediately be unclear if factors are not labelled correctly. A first alert should be that a fellow modeller asks for clarification of certain causal relations. Conceptual models should be self explanatory as much as possible. If explanations are really necessary, one should consider a redesign of the model rather than 'repairing' inconsistencies with explanatory text.

Conceptual chain pitfall

The conceptual chain pitfall relates to the consistency of the analysis. Students often forget that there is a methodology for performing the analysis that links the different methods with a flow of information from one step to the other. Every method has its own objective of analysis, but the information produced/derived comprises the input for another method of the analysis [6] [7]. The pitfall of the students is that over the course of their modelling exersize they perform every method correctly but in their deepening into the methods they overseen the integration of the modelling steps to the broader methodology. By not linking back to the methodology (and disintegrate the mdelling steps), the outcome of their analysis is inconsistent.

The conceptual chain pitfall arises from the fact that students do not realize the aim of the analysis. Reference [8] (p.5) provide a definition of a policy that reveals the conceptual chain of the different methods: "Policy is a purposive course of action in pursuit of objectives based upon careful assessment of alternative ways of achieving such objectives and effective implementation of the selected course of action" (see Appendix A, Table A.2). An example of a conceptual chain illustrates better our point (Figure 3):

Method	**Goal hierarchy**	⇨	**Target analysis**	⇨	**Causal relation diagram**
Information	Lower level objectives		Values of lower-level objectives		Factors related to lower-level objectives to start analysis

Figure 3. A conceptual chain of policy analysis methods that shows the flow of information and the relationships among the methods (the outcome of one method feeds into the next method).

Analysis communication pitfall

The last step of the analysis (policy choice) has to include a description of the recommended (by the analysis) alternatives and their policy impacts [9] in dealing with the problem. Potential side effects, constraints (aspects of the system that may inhibit or burden its implementation), and limitations of every alternative are also expected to be presented. This information on the policy alternatives, however, is often not included or is neglected by inexperienced policy analysts (students). Other forms of this pitfall are that students forget to link the alternatives to the actor, to the problem, and to the objectives defined, and/or present only one alternative as "the best" one and do not present the second- or third-ranked alternatives.

4. FIVE ACTIONS COPING WITH PITFALLS WHEN PERFORMING CONCEPTUAL MODELLING

Transferring modelling skills requires true engagement of the students in the actual modelling effort. Only when students discuss the grammar of the language, the choices of demarcation and representation, and the consistency and completeness of the model, will they acquire the modelling skills. The first and key action we take is to *include collaborative workshops* in the curriculum of modelling learning courses so as to facilitate learning how to work in groups. The benefits of both group work and of (the specific set-up of) collaborative workshops for acquiring modelling skills have been discussed in [3] and include self-reflection of students in their models, active involvement in the modelling exercise, and development of confidence when dealing with modelling throughout the modelling workshops. After spotting one or more of the pitfalls described above, we have applied and tested different actions during collaborative modelling workshops in which students form groups and exercise the policy analysis methodology (see Table 3). These actions concern our suggestions to students when we detect/observe that they are struggling with the analysis due to the presented pitfalls. We encourage and motivate students first to self-reflect and correct their own models by asking them questions that aid them in realizing the pitfalls they have made. The suggestions given by teachers to overcome the pitfalls are presented below.

Table 3. Actions to overcome pitfalls that are experienced when performing a policy analysis study.

Characteristics of a good policy analysis study	Pitfalls	Actions to overcome pitfalls
Replicability		
Comprehensiveness	Abstraction pitfall	Reiterate
Conciseness	Labelling pitfall	Rename or remake
Consistency	Conceptual chain pitfall	Keep in mind the "big picture" Check and double-check
Applicability	Analysis communication pitfall	Return to the roots

Reiterate

The abstraction pitfall threatens the comprehensiveness of the analysis. A starting question for checking whether the comprehensiveness quality attribute is satisfied is: *what are the dimensions of the problem?* or better*, what are the areas of influence and what are the possible sources related to the problem?*

Iteration and reiteration of the analysis steps of the conceptual methods is required to ensure that the level of abstraction is suitable to the problem. What is actually performed is a continuous reiteration of the level of abstraction and the content of factors included in the conceptual models e.g. Causal relation diagram so as to arrive to the adequate level of abstraction for the problem investigated. An reiteration action (that is suggested to the students and permormed in class with them) refers to a cycle where you 'select-check-revise-select' every concept placed in a conceptual model. Specifically for abstraction pitfalls experienced when dealing with goal hierarchy, the reiteration action inititated by asking 'why' when formulating a goal until you get to a high level of abstraction. Immediately after that, ask what this abstract goal means in light of the specific problem. In such a way, already the first set of sub-goals is related to the problem. A too narrow level of abstraction can be solved by asking how

many potential solutions may influence a certain goal. Goals that can be influenced by only one potential solution should be critically reviewed.

A continual iteration and reflection of the by asking the right questions aids in clarifying the concepts and setting them to the level of abstraction that is adequate for the problem under investigation.

Rename it or remake it!

The labelling pitfall threatens the conciseness of the policy analysis study. A starting question for checking whether the conciseness attribute is satisfied is: *how does this area of impact/ area of analysis/ component of the system relate to the problem under investigation?*
After determining what is to be included in the analysis, the conciseness of your factors in the way they are labelled/named needs to be checked. Here you need to indicate whether the units of a factor agrees with the name of the factor. If there is a mismatch, the factors need to be renamed and, in the worst case, the causal diagram or the objectives tree needs to be remade instead of just plugging in text to explain causal relations that are unclear or clarify objectives that appear in the objectives tree. The causal relation diagram and goal hierarchy need to be self-explanatory and indicative for the problem under analysis. Explanation in text accompanies the diagrams to provide an in depth elaboration of the relations so as to back the factors present in the diagrams, but not to explain a 'badly' named factor.

Keep the big picture in mind

The conceptual chain pitfall deteriorates the consistency of the analysis. A starting question so as to check the consistency of the analysis is: *how does this alternative (or factor) relate to the problem under investigation?* For consistency to be kept and ensured, students need to cross-check whether the information from one step of the analysis is transferred to the next step. For students to avoid knowledge segmentation when performing the methods of every step as separate tasks, the "big picture" needs to be kept in mind. This can be realized by either showing the information that needs to flow from step to step (see Figure 2, for example) or by assigning the students to draw a structure of the analysis (that actually draws upon the steps of the policy analysis).
Our motto to students here is to "think outside the box, even though you think for the box". We expect from novice policy analysts at this stage to surprise us with innovative ideas ("outside the box") to deal with the problem as outcomes of their analysis.

Check and double-check

This action refers to the intensive and critical examination of the consistency between the steps of policy analysis. It is complementary to the previous action, and aims at improving the level of consistency by checking whether all the concepts used in one step are kept and taken into account in subsequent steps of the analysis. A check of the figures of conceptual models most of the times is sufficient for an experienced or aware analyst to assess consistency, but less experienced analysts require at least two checking-rounds. What we encourage and teach policy analysis students to perform is to check whether the outcomes of one modelling step have been fed in the next modeling step (or from one method to the next method) in their exact form. An example here is our frequently mentioned advice/question when moving from goal hierarchy to assessment of policy alternatives in constructing impact tables so as to check consistency: Do you transfer the lower-level objectives of your goal hierarchy with their units as they appear in the impact table?

Return to the roots

This recommended action includes two aspects: a return to the start of the analysis in order to link any recommended policy alternative to the problem, the objectives, and the actors, and a return to the purpose of the analysis, which is not to identify the "optimal" or "best" alternative, but to identify a package of robust policy alternatives -- policy alternatives that are expected to perform well under different plausible scenarios. We realize this by suggesting that the students present the alternatives they come up with and asking them: *What does this mean for your actor/client? What is the impact of this alternative? Why are you recommending this policy alternative*?

5. REFLECTION AND CONCLUSIONS

During our modelling courses and the collaborative modelling workshops we perform, we noticed that students faced difficulties in modelling and run into a distinct set of pitfalls when the try to model. We defined four common and distinct pitfalls: abstraction pitfall, labelling pitfall, conceptual pitfall and analysis communication pitfall. In this paper we have given clear descriptions of each, so they are more easily recognizable. It is noteworthy that these pitfalls restrain junior analysts from delivering a thorough and qualitative analysis given that they deteriorate the analytic content-quality of a study in which modelling is the core analytic method. Systematic problem solving requires not only analytical skills and creative thinking but also practising and gaining experience with the methodology and the methods.

Given our experience in teaching modelling to graduate students, we also practice and test different types of actions with which we guide students to overcome those pitfalls by self-evaluation of their own model and analysis. There are five recommended actions included in this paper, for which we provide concrete descriptions of how we apply them in practice. We labelled them as follows: (1) reiteration, (2) renaming or remaking, (3) keeping the big picture in mind, (4) returning to the roots, and (5) checking and double-checking. Those actions have been proven successful in overcoming the modeling pitfalls when learning conceptual modeling.

Further research on the effectiveness of alternative teaching approaches during the collaborative workshops, e.g. reflection exersizes with the presentation of material that clearly show the pitfalls might provide us with more insight over the underlying causes of the pitfalls and insights to improve quality of teaching methods. Collaboration with more modeling instructors may also benefit our research and verify the delineation of the modeling pitfalls by gathering evidence for the experience of those pitfalls in other contexts.

Last but not least, we believe that by revealing and indicating the modelling pitfalls we have provided insights to teachers of modelling techniques so as to improve their education methods and approaches. We believe that our systematic way of describing the pitfalls and of including the tested actions will make it easier for teachers and supervisors to reflect on their education practices and to guide junior modellers in building better models.

APPENDIX A

Table A.1 Methodology and various methods (for every step) of policy analysis.

Steps of policy analysis (methodology)	Methods of policy analysis
Conceptualization	System diagram Actor analysis Network analysis Objectives tree
Specification	Causal relation diagram Means-ends diagram
Alternatives generation	Brainstorming Searching Dominance AIDA etc.
Dealing with uncertainty	Scenario analysis Risk analysis
Assessing policy impact	Simulation models Analytical models Qualitative models
Screening	Dominance Even Swaps Scorecard Multi-criteria analysis Contingent valuation Conjoint analysis

	Cost-benefit analysis Cost-effectiveness analysis
Evaluation and Implementation	Feasibility analysis, etc.

Table A.2. How the steps of policy analysis are linked in one definition.
The conceptual chain pitfall arises from the fact that students do not realize the aim of the analysis. [6] (p.5) provides a definition of a policy that reveals the conceptual chain of the different methods: "Policy is a purposive course of action in pursuit of objectives based upon careful assessment of alternative ways of achieving such objectives and effective implementation of the selected course of action"

Steps of policy analysis (methodology)	**Components of the policy definition that show the interconnectedness of the steps**
Conceptualization	purposive course of action
Specification	in pursuit of objectives
Alternatives generation	ways of achieving such objectives
Dealing with uncertainty	based upon careful assessment of alternative ways
Assessing policy impact	
Screening	
Evaluation	effective implementation of the selected course of action

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