Reasoning Types in Industrial Engineering/Operations Management Processes

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Abstract

Operations Management/Industrial Engineering modeling process entails a series of research paradigm decisions to be made as to (1) what the reality domain is - ontology, (2) how the problem domain is to be defined and theorized - epistemology, and (3) which solution domain is to be considered – methodology; and all three being based on axiological assumptions entailing ethical concerns. These paradigm-related decisions need to be based on a series of sound reasoning activities. In this regard, three types of reasoning – abductive, deductive and inductive – will be discussed in connection with a scheme of Operational Research/Management Science modeling process.

1. Introduction

It is interesting to observe that the reasoning types of abduction, induction, and deduction have not been made much of a concern in the Operations Management/Industrial Engineering. There are only very few studies that explicitly examines the roles of reasoning types in modeling process. In neighboring fields, however, such as System Dynamics, Cavana and Mares (2004) explicitly use deductive reasoning to justify a policy that was already put into practice. Organization Science researchers, on the other hand, are more verbal and vociferous about the roles of reasoning types in research. For instance, Ketokivi and Mantere (2010) suggest two strategies for inductive reasoning in organizational research. Van de Ven (2007) discusses the roles of abduction, induction, and deduction at some length in connection with theory building.

We assert that there is a need for a sound understanding of the roles of abduction, induction, and deduction in all stages of a modeling process. Well-informed uses of this triad of syllogism will enhance modeling process since the models thus constructed will be more valid and legitimate in the eyes of relevant stakeholders – model builders, model users, and model assessors.
The organization of this paper is as follows. The next section, Section 2, presents a representative scheme of modeling process in Industrial Engineering/Operations Management. Section 3 provides a background on the nature of abduction, induction, and deduction methods. Section 4 is devoted to the explanation of syllogism in modeling process. Section 5 offers some discussions. And Section 6 concludes the paper.

2. Industrial Engineering/Operations Management Modelling Process

Modeling process, emphasis being mostly on model itself though, has been always at the center of IE/OM studies since its naissance in 1940s. Many articles have appeared since then in IE/OM related journals dealing with the issues of model-building, model validation, and model legitimization. In most recent editions of some classical books on OR/MS, such as Hillier and Lieberman (2005), and Taha (2011), the number of modeling steps for problem-solving is given as either six or seven.

Our discussion however draws primarily on the articles of Franco and Montibeller (2010), Kirby (2007), Landry (1995), Oral and Kettani (1993), and Landry et al (1983). As a synthesis of these well-known articles, we consider a four-stage iterative modeling process, as depicted in Figure 1: (1) conceptualization – from “managerial situation” to “conceptual model,” (2) model building – from “conceptual model” to “formal model,” (3) solution obtaining – from “formal model” to “decision,” and (4) implementation – from “decision” to “managerial situation.”

Conceptualization: The process of conceptualization involves both defining “managerial situation” and constructing a corresponding “conceptual model.” As Beer (1984) and Oral and Kettani (1993), we prefer to use the term “managerial situation” rather than the term “problem.” In our opinion, “managerial situation” is more comprehensive than a “problem,” for it embraces more. “Managerial situation” could be, for instance, a “problem” to be solved or removed; or an “assessment” to be made to position a company or organization vis-à-vis others; or a “prediction” to foresee likely opportunities and threats ahead; or an “analysis” to better understand the factors governing a system and its very environment. Referring to Oral and Kettani (1993), “managerial situation” is basically a perception of the real world as formed by decision makers or major actors. Any perception that attracts...
the attention and effort of relevant actors is a “managerial situation.” Put differently, “managerial situation” is an abstraction of a certain set of real world events as an attention-allocation device to set up an agenda for future analysis and solution efforts.

**Model Building:** “Conceptual model,” being a theory, cannot be observed directly. Therefore, there is a need for a mediator that will connect the “conceptual model” to the data corresponding to the reality or the “managerial situation” as defined or perceived. This mediator is a “formal model” in OM/IE. Expressing and representing the “conceptual model” as faithfully and accurately as possible in a language of choice (mathematics, computer codes, graphs and figures) leads to construction of a “formal model.” The primary objective of constructing a “formal model” is to be able to systematically study the “managerial situation” in order to better understand it and obtain solutions, optimal or satisfying, for formulating decisions.

**Solution Obtaining:** “Decision” is a conclusion as to which alternative course of action is to be taken; which solution or recommendation is to be implemented; or which areas or issues are to be given more managerial attention. The “formal model” is the source from which solutions or alternatives can be obtained with their likely consequences. If the “formal model” constructed for this purpose has the properties of reflecting the perceptions, values, objectives, and knowledge of the relevant actors at a satisfactory level, then the solutions can be taken as “decision” directly or with some modification. The process of obtaining solutions depends considerably on the complexity level of the “formal model” constructed.

**Implementation:** The primary objective of carrying out a “decision” is to achieve an array of intended favorable results in connection with “managerial situation.” Put differently, OM/IE strives for making a contributive difference or a positive impact by implementing the results of the study done. To create a favorable impact, there are some basic requirements that must be met: (1) “decision” and the way it is formulated through the modeling process employed must be understood by the group of implementers or the relevant actors, (2) the modeling process and its outputs, in addition to being understood, must be accepted as a legitimate process producing legitimate results, (3) there must be a commitment on the part of relevant actors to implement the results, and (4) necessary resources and time, at the commitment level considered, need to be allocated for implementation.

3. The Triad of Syllogism

This section is devoted to a brief discussion of three reasoning types in logic; namely, deduction, induction, and abduction. Figure 3 summarizes the three types of reasoning in logic as presented by Niiniluoto (1999) using the classical examples of Charles S. Peirce (1839-1914), an American philosopher and the founder of pragmatism.

**Deductive Reasoning:** It starts with the assertion of a “rule” (also termed “major premise”) and proceeds from there to reach a guaranteed conclusion about a “result” through a “case” (also termed “minor premise”). Deductive reasoning is true if the major and minor premises are true. Deduction is the basis of many arguments in daily life as well as in mathematics and science. Mathematics as the language of science requires absolute consistency and transparency in its statements and deductive reasoning is the means of advancing such totally consistent arguments. However, deductive reasoning does not produce any new knowledge since it produces basically tautological statements, saying the same thing differently. The things to be known are given in the premises and the result is but self-evident. Although deduction does not produce any new knowledge, it is an important reasoning type in building a theory. Theory consists of several concepts and these concepts need to be related to one another in a consistent manner to explain the phenomenon of interest.

**Inductive Reasoning:** The “case,” and the “result” obtained from the “case” are used to make an inference about the “rule.” This statement implies that we have some observations or empirical data about the “rule,” albeit they might be specific and limited in scope, and we use the findings from these observations or empirical data to claim a generalized conclusion about the “rule.” Put differently, we don’t know much, if at all, about the “rule” and we make observations about the “rule” to come up with a general statement about the “rule.” In that sense, induction is an amplifying form of reasoning because the conclusions reached are more than restatements of the premises and involves the drawing of conclusions that exceed the information contained in the premises. Since the conclusions of inductive arguments contain more information than all their premises combined together, induction method is knowledge expanding, which is the primary objective of any science. Because science seeks to establish general knowledge that goes beyond the data collected or observations made, it must use inductive reasoning. However, we cannot be sure about inductive conclusions because of the lack of complete set of data or observations corresponding
to the entirety of premises. Therefore, the conclusions reached by inductive reasoning are not logical inevitabilities due to the fact that no amount of inductive evidence secures the conclusion.

**Figure 2: Three Reasoning Types in Logic**

**Abductive Reasoning:** Abduction is the inference about the “case” from the “rule” and “result.” Given the “case,” which could be an anomaly, a problem, a managerial situation, a previously unimaginable, or an unthinkable circumstance, which “rule” and “result” can best explain or account for the “case?” Abductive reasoning is different from inductive one in an important way: the latter concentrates on the “rule” under investigation through different cases whereas the former focuses on the “case” and searches for the “rule,” among several alternatives, that explains the “case” of interest best. Tautologically speaking, in induction method, the “rule” is fixed and one tries to understand it though varying cases whereas in abduction method the “case” is fixed and one tries to explain it by varying plausible “rules.” According to Peirce’s theory of abduction, abductive reasoning is towards a hypothesis whereas inductive reasoning is from a hypothesis (Fann, 1970). Abductive reasoning starts with a set of data or observations that deserves or awaits an explanation – towards a hypothesis. This explanation could be a theory, a hypothesis, an assumption, a proposition, a diagnosis, a judgment, or simply a guess. One way or another, the “case” needs to be understood, albeit in general terms that could be refined later if needed. This is the very role of abductive reasoning without which the “case” remains inexplicable fact or observation. Juxtaposing the unfamiliar with the familiar is the essence of abductive reasoning. While abductive reasoning is searching for new ideas, deduction and induction methods deal only with a set of selected ideas.

When abduction is compared with induction, they are similar in that both aim at producing new knowledge, albeit differently. In induction method, new knowledge production is constrained by the selected hypothesis (which can be considered as probable) whereas abduction is guided by a surprising situation to invent hypotheses (which
can be considered as plausible. In that sense, abduction can be interpreted as an inductive method loosened to come up with any set of plausible hypotheses or explanations; rather than concentrating on only one hypothesis as induction method does. From a “systems” perspective, deductive reasoning operates within a well defined “closed” system of “premises”, whereas inductive and abductive reasoning types go beyond the “premises” and therefore take place in an “open” system.

4. Syllogism in Modelling Process

The three types of reasoning - abduction, deduction, and induction – although discussed one by one separately, they are mostly operative collectively and supportively in every stage of an IE/OM modeling process, as will be discussed in this section. Their sequence and dominance level, however, might change from one stage to another in a modeling process, as it is shown in Table 2.

**Reasoning Types in Conceptualization:** Conceptualization stage entails both “managerial situation” – research issue or problem; and “conceptual model” – in fact a theory. “Managerial situation” is in essence finding or identifying a “surprising fact” or an “anomaly” that needs to be dealt with. In this context, a “surprising fact” could be a problem to be solved, launching a new product, developing a new technology, formulating competitive strategy, entering a new market, coming up with a new idea of any kind, or any issue that is not a matter of a routine course. This “surprising fact” or “managerial situation” is to be understood and explained in the best way possible. This is the kernel of abduction method. Therefore, “managerial situation” and abductive reasoning coexist and one without the other is incomplete. Finding or creating a best explanation for a “managerial situation” needs to be done in a logically consistent and transparent manner, a process that stipulates deductive reasoning. In other words, abductive method is to be supported by deduction while communicating “managerial situation” to others. In order to convince others even more, analogies and metaphors can be used as an application of inductive reasoning. In summary, abduction is sensemaking about the reality to define a “managerial situation” whereas deduction and induction are sensegiving to others about “managerial situation.”

The resultant of conceptualization is a “conceptual model.” We have already established that “conceptual model” is but a theory. In that theory, we need new concepts that are related to the “managerial situation.” These new concepts are to be conceived or invented by abductive reasoning. Constructing a set of relationships between the concepts is to be achieved by deductive reasoning; and finally the set of relationships between the concepts are to be justified by inductive reasoning.

In summary, for the conceptualization stage, the dominance order of reasoning types, as indicated in the last column of Table 2, is as follows: (1) abduction, (2) deduction, and (3) induction.

**Reasoning Types in Model Building:** The process of model building takes “conceptual model” and converts it into a “formal model” through suggesting/stating propositions between constructs, if the abstraction level is high; and formulating the hypotheses between variables if the abstraction level is low. Formulating hypotheses (in the forms of statistical or optimization models) are more frequent in the IE/OM field and mathematics is usually the instrument for this conversion. “Formal model” is expected to mimic as much as possible the “conceptual model.” As such, the consistency and verifiability of models become main concerns in this stage and these properties are secured primarily by deduction and induction, and then by abduction if new ideas are needed in model building methods.

**Reasoning Types in Solution Obtaining:** This stage is similar to the model building stage in that both have the same dominance order; that is, deduction, induction, and abduction. Solution obtaining stage requires the development and use of algorithms where deductive reasoning is unavoidable, simply because modeling language is mostly mathematics or mathematics-based devices. The solutions obtained from the formal model are to be justified in the sense that they are meaningful in empirical terms. This is where inductive reasoning is in demand. Regarding abduction, many new algorithms or techniques necessitate conceiving new theories and hypotheses. Conceiving new ideas and theories, as stated before, require abduction method.
Table 2: Reasoning Types in IE/OM Modeling Process

<table>
<thead>
<tr>
<th>Modeling Stage</th>
<th>Connected Resultants</th>
<th>Dominance Order and/or Sequence of Reasoning Types</th>
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| Conceptualization - Reflecting Ontological Assumptions | Managerial Situation and Conceptual Model | 1. Abductive  
2. Deductive  
3. Inductive |
| Model Building - Reflecting Epistemological Assumptions | Formal Model corresponding to Conceptual Model | 1. Deductive  
2. Inductive  
3. Abductive |
| Solution Obtaining - Reflecting Methodological Assumptions | Solution Methods and Techniques | 1. Deductive  
2. Inductive  
3. Abductive |
| Implementation - Reflecting Axiological Assumptions | Decisions and Managerial Situation | 1. Inductive  
2. Abductive  
3. Deductive |

**Reasoning Types in Implementation:** The success of any implementation is very much dependent on the acceptance level of the model built and the solutions obtained from it. In this stage, it is necessary to inductively show that the model and solutions are empirically justifiable. Moreover, the actionable knowledge thus suggested/produced has the potential to deal with the “managerial situation.” Whatever the anomaly or surprising event implied by the “managerial situation,” the suggestion/solution obtained is the best or nearly the best response possible – requiring abduction. These two reasoning types are to be supported by deduction method for consistency and transparency in communicating the model and solutions to other stakeholders. Thus the dominance order of reasoning types suggests itself as induction, abduction, and deduction, as shown in Table 2.

5. Discussion

Given that modeling process is in essence an actionable knowledge or theory production process, then we can claim that the three reasoning types are to be used in such a manner that they support and complement one another. The integrating dynamics of syllogism in this sense is depicted in Figure 3.

It is appropriate to give some concrete examples where abduction is supported by deductive and inductive methods. Structural Equation Modeling (SEM), a multivariate statistical analysis technique, is a tool which starts with a set of data. So, the “case” is given and fixed. The objective is to come up with a structural model that explains the data in the best way possible. For this very purpose, researchers usually develop a measurement model first through explanatory factor analysis (EFA) – in the absence of theory about structural relationships between constructs or latent variables, and then validate them with confirmatory factor analysis (CFA). Once the measurement model passes the validity tests, then structural model is built to express the interrelationships between the constructs in a series of linear regression equations. From the perspective of syllogism, SEM is completely faithful to the data, which is the main feature of abduction, and seeks and tests theories – which are structures that link observable variables and unobservable, but useful latent constructs, that are consistent with the data. This abductive approach of SEM is however formally performed through a completely deductive reasoning. Therefore the domain of abductive reasoning is constrained by the basic methodological assumptions of SEM – which are
entirely provided by deductive reasoning; for instance, all the relationships between variables and constructs are linear and no feedback is allowed.

![Figure 3: The Integrating Dynamics of Syllogism in Modeling Process](image)

The dominance of deduction and induction, and especially that of deduction through the “mathematization” of IE/OM, in the “positivist/scientist” tradition/approach of IE/OM has been the main issue of considerable debate as to the validity and legitimacy of the models developed for the purpose of organizational interventions. This dominance of hard paradigm has later created what is called “crisis in IE/OM” to which British and European researchers were more responsive than their US counterparts (Kirby, 2007). Pursuing hard paradigm has produced models that were not only self-limiting because of their excessively complicated mathematics (Ackoff, 1973) but also counter-performing in organizations and thus diminishing their possible effectiveness in interventions.

Admitting the gap between theory and practice, a group of IE/OM researchers, in UK and Europe as well as in USA, identified the main cause as the model builders’ lack of understanding the reality as perceived by model-users and problem owners. As a remedy, engaging all major actors in modeling process, especially in the stages of identifying and formulating problems, has become a necessity. For this purpose, several approaches and methods have been developed and used successfully in practice (Mingers, 1997, 2003). Among these are “problem structuring methods,” “soft systems methodology,” “multi-methodology,” “facilitated modeling,” and “cognitive mapping.” This is an important shift in IE/OM in terms reasoning types as well. Now, abduction is also becoming, although implicitly, a part of modeling process, in addition to deduction and induction.

One last point regarding paradigmatic assumptions of modeling process, the ontological assumptions gives prominence to doing the right things whereas epistemological and methodological assumptions to doing the things right. Axiological assumptions, on the other hand, aim at securing the paradigmatic assumptions well confirm to a set of acceptable ethical requirements.

6. Concluding Remarks

The importance and roles of the three types of reasoning in logic are discussed in connection with the stages of a modeling process in IE/OM field. Although it is not explicitly stated yet, there is tendency to move from the deductive and inductive dominance (hard IE/OM to abductive dominance (soft IE/OM) as concentration intensifies.
on engaging all major actors in modeling process. It is thought and hoped that IE/OM researchers will make use of abduction, deduction, and induction methods more explicitly in their future work. Particularly, the usefulness of abduction in generating new ideas in problem formulation and theory building will be recognized and new avenues will be opened for abductive reasoning in addition to those for deduction and induction.

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