Necessary Condition Hypotheses in Operations Management

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ABSTRACT AND KEYWORDS	
Abstract	Purpose – To show that necessary condition hypotheses are important in operations management, and to present a consistent methodology for building and testing them. Necessary condition hypotheses ("X is necessary for Y") express conditions that must be present in order to have a desired outcome (e.g. "success"), and to prevent guaranteed failure. These hypotheses differ fundamentally from the common co-variational hypotheses ("more X results in more Y") and require another methodology for building and testing them. Design/methodology/approach – Reviewing operations management literature for versions of necessary condition hypotheses. Combining previous theoretical and methodological work into a comprehensive and consistent methodology for building and testing such hypotheses. Findings – Necessary condition statements are common in operations management, but current formulations are not precise, and methods used for building and testing them are not always adequate. Outline of the methodology of Necessary Condition Analysis (NCA) consisting of two stepwise methodological approaches, one for building and one for testing necessary conditions. Originality/value – Because necessary condition statements are common in operations management, using methodologies that can build and test such hypotheses contributes to the advancement of operations management research and theory.
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Conceptual Paper

Necessary Condition Hypotheses in Operations Management

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Necessary Condition Hypotheses in Operations Management

Abstract

Purpose – To show that necessary condition hypotheses are important in operations management, and to present a consistent methodology for building and testing them. Necessary condition hypotheses ("X is necessary for Y") express conditions that must be present in order to have a desired outcome (e.g. "success"), and to prevent guaranteed failure. These hypotheses differ fundamentally from the common co-variational hypotheses ("more X results in more Y") and require another methodology for building and testing them.

Design/methodology/approach – Reviewing operations management literature for versions of necessary condition hypotheses. Combining previous theoretical and methodological work into a comprehensive and consistent methodology for building and testing such hypotheses.

Findings – Necessary condition statements are common in operations management, but current formulations are not precise, and methods used for building and testing them are not always adequate. Outline of the methodology of Necessary Condition Analysis (NCA) consisting of two stepwise methodological approaches, one for building and one for testing necessary conditions.

Originality/value – Because necessary condition statements are common in operations management, using methodologies that can build and test such hypotheses contributes to the advancement of operations management research and theory.

Keywords: Necessary Condition Analysis (NCA), logic, methodology, theory building, theory testing, critical success factors

1. Introduction

Assertions such as “Promotion of employee responsibility is a necessary condition for JIT flow” (McLachlin, 1997), and “No doubt that top management commitment is necessary for the success of many of these techniques [such as MRP, JIT, TQM and BPR]” (Youssef, 1998: 808), or more generally “X is a necessary condition for Y” or “X is a necessary but not sufficient condition for Y,” are commonplace in the operations management literature. This is particularly true in articles aimed at managers or in discussions of the managerial implications of research papers. Such statements imply very specific hypotheses that are different from the usual co-variational hypotheses (“more X results in more Y”). In addition, hypotheses about necessary conditions require distinctive approaches for building and testing, and an examination of academic papers will quickly reveal that appropriate approaches have rarely been conducted. As a result we cannot tell if statements expressing necessary conditions are supported by the data.

In Operations Management (OM), the ability to build and test such hypotheses is important, and this paper sets out to indicate how this might be done. The paper explores how necessary condition hypotheses can be built and tested in different research contexts in OM, including case studies and large-scale surveys, or when using objective data. In addition, it is argued that data sets with statistical problems such as heteroscedasticity may in fact reveal the existence of necessary conditions.

In this paper we aim to enhance researchers’ and practitioners’ understanding of necessary condition hypotheses and assist them in their efforts to build and test them. We structure our paper as follows. In section 2 we define necessary conditions hypotheses. We then present examples of necessary condition hypotheses in the OM literature, discuss the relevance of such hypotheses, and present some common methodological issues when building and testing them. Next we present a comprehensive and consistent methodology for building necessary condition hypotheses from cases (section 4), and subsequently for testing necessary condition hypotheses with cases (section 5), each illustrated with an OM example. In section 6 we extend the analysis to continuous necessary conditions. Finally we draw conclusions and give recommendations.

2. Necessary condition hypotheses

The formal expression of a necessary condition hypothesis is "Y only if X". (Braumoeller and Goertz, 2000; Goertz and Starr, 2003). This can be expressed in different ways such as "condition X should be present in order to make outcome Y possible", "Y is very unlikely to occur if X is absent", or "Y normally is not possible without the presence of X". Necessary condition statements can also be expressed in other ways without using the word "necessary" as shown in Table 1.

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Insert Table 1 about here

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We can illustrate this concept of necessary conditions with a simple case in which an independent variable X can have two values (0 or 1; absent or present) and a dependent variable Y (the outcome) can also have two values (0 or 1; absent or present), as in Figure 1.

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Insert Figure 1 about here

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The necessary condition is *defined* by the combination X(0) and Y(1) not being possible. If a necessary condition is present (X=1), this does not *guarantee* that the outcome will occur (Y=1) but only that the outcome has become *possible*. Or, in other words, a necessary condition is not automatically also a sufficient condition. The frequently used phrase "necessary but not sufficient condition" is a very appropriate reminder of the fact that the concepts of necessary and sufficient conditions differ.

So far, we have defined a necessary condition as possible and not possible combinations of specific scores of two dichotomous variables (or dichotomized continuous variables). Possible scores for each variable are only 0 and 1 (or absent and present). The condition is a state or an event that must be present (X=1) in order to have the outcome (Y=1). Often the condition is a single variable (Braumoeller and Goertz, 2000), for example in "change can only be successful if there is *management commitment*". In this example a certain level of management commitment is the necessary condition that must be present for success. The condition can also be a configuration of a set of variables (Fiss, 2007). An example is: "success is only possible if both *management commitment* and *financial resources* are present" or, in other words, if the configuration of *management commitment* and *financial resources* is present. Both forms of necessary condition can also include a time element: a single variable or configuration must be present at the right time. An example is: "a project can only be successful if there is *management commitment at the start of the project*". Time ordering of events is an essential element in process theory approaches (Mohr, 1982; Jaspers *et al*., 2008). However, necessary condition statements can also involve variables with more than two possible discrete values. We will discuss examples from OM research below. It is also possible to formulate necessary condition hypotheses about variables that are continuous. We will discuss such hypotheses in section 6 of this paper.

3. Necessary condition hypotheses in operations management

Necessary condition hypotheses are important types of hypotheses that are common in many fields including operations management. As Goertz and Starr note: "for any research area one can find important necessary condition hypotheses" (2003: 65-66). We reviewed four major ISI operations management journals: Journal of Operations Management (JOM), International Journal of Operations and Production Management (IJOPM), Production and Operations Management (POM), and Manufacturing and Service Operations Management (MSOM). We performed a full text search in all papers from the launch of these journals (1980, 1980, 1992, and 1999, respectively) until 2008 using the keyword strings "necessary condition", "necessary and sufficient condition" and "necessary but not sufficient condition". We found 107 papers with necessary condition statements (45 in JOM, 30 in IJOPM, 18 in POM and 14 in MSOM). After reading these papers, we excluded papers in which (a) the necessary condition statement was not, strictly speaking, meant as the formulation of a necessary condition statement but rather as an "important condition", apparently not referring to the meaning of "necessary" in logic as discussed above, and those in which (b) the necessary condition statement was not a theoretical statement. In many mathematical modelling papers, for instance, necessary condition statements often refer to mathematical conditions that are needed for, e.g., optimality, and in statistical sections of papers necessary condition statement often refer to, e.g., conditions for applying a statistical analysis. After excluding these statements that were not relevant for our purposes, 32 examples of necessary condition hypotheses remained: 20 in JOM, 11 in IJOPM, one in POM and none in MSOM. This set represents probably only a subset of the necessary condition hypotheses in these journals because these examples were selected by using the explicit phrase "necessary condition" as a search term. A search with synonyms (such as listed in Table 1) was not conducted.

3.1. Examples

Necessary condition statements in OM are particularly common in studies on the determinants of the successful implementation of OM practices such as BPR, JIT, TQM, ERP, etc. For example, Youssef (1998: 808) states: “Most of the reasons cited in literature for [failure] was lack of top management commitment. No doubt that top management commitment is necessary for the success of many of these techniques.” Mersha (1997: 170) states that “there are certain necessary conditions for the successful implementation of TQM”, and Mohanty and Deshmukh (1999: 325) when discussing organizational learning argue that: “vision is the precondition and the only necessary condition for the promotion of coexistence of collective creativity and efficiency”. In a comprehensive study on necessary conditions for JIT implementation, McLachlin (1997) formulated 20 necessary condition hypotheses. We will discuss this study in detail in section 4. In another example, Narasimhan and Jayaram (1998) explore key factors for successfully planning and implementing business process reengineering efforts. They conclude that: “Approval by the stakeholders is critical in all three stages of the BPR initiative… [E]ffective completion of a preceding stage is a necessary condition for the effective completion of the subsequent stage.” (p. 21). The authors build a process model of three main stages (A, B, C) in which successful completion of A is necessary for B and successful completion of B is necessary for C. Within all three stages there are necessary conditions for successful completion. Kleindorfer and Saad (2005) presented a framework for the management of disruption risk in supply chains, and in the discussion section they suggest that there are two necessary conditions for successful implementation of the framework in practice: “[I]t is important to stress the importance of two final observations or “conditions” that are necessary for effective implementation: Condition C1. The approaches used to mitigate disruption risks must “fit” the characteristics and needs of the underlying decision environment…..Condition C2. Continuous coordination, cooperation, and collaboration among supply chain partners are needed for risk avoidance, reduction, and mitigation.” (p. 66).

3.2. Managerial relevance

In OM an important synonym for necessary is “critical” such as in “critical success factors” (CSFs): factors or conditions that are “critical” for the success of managerial practice such as the implementation of JIT, TQM, BPR, and ERP. In the context of ERP implementation, CSFs have been defined as “factors that, to a great extent, determine whether the implementation will be successful” (Umble *et al*. 2003: 244). Earlier, Pinto and Prescott (1990: 306) defined a set of CSFs as “a variety of critical factors … that can improve significantly the likelihood of project implementation”. The term “significant” in this formulation does not refer to significance levels in the statistical sense but to the size of the influence on the likelihood of (achieving) implementation. Ranjan and Bhatnagar (2008) explicitly define CSFs as a necessary condition: “Critical Success Factor (CSF) is a business term for an element which is necessary for an organization or project to achieve its mission”.

The above and other examples show that necessary condition statements are important for OM practice. If a manager wants to achieve a desired outcome (“success”) then the necessary condition statement, if correct, implies that it is critical or essential for the manager to make sure that this condition is in place because success will not be possible without it. This does not imply, however, that the presence of the necessary condition guarantees success. For multi-causal phenomena, other conditions might be necessary for success as well. Success is guaranteed only if all necessary conditions are known and realized and if the set of these necessary conditions is sufficient for success. However, only rarely all relevant necessary conditions are known. Therefore, implementing known necessary conditions normally only increases the likelihood of success. But *not* implementing a known necessary condition guarantees failure. This might be one of the reasons why so many implementation processes result in failure, and might also explain the phenomenon that often, even in a situation where success is present initially, failure suddenly occurs at a later stage. A successful implementation is the result of an often arduous process in which a large number of factors that contribute to success must be realized, but taking away (or a deterioration of) a single necessary ("critical") condition will result in failure: "Success comes on foot and leaves on horseback".

3.3. Methodological issues

In reviewing the use of necessary condition statements in OM, we observe a number of methodological issues. The first is seeking to make statements about necessary conditions for success (or for other outcomes) when the data only concerns cases without the outcome (e.g. cases with failure). For example, Fullerton and McWaters (2001: 93) state that "Case studies of JIT failures would provide information on the pitfalls of JIT and the necessary conditions for its success". However, when the outcome is absent the value of the condition (absent or present) is not relevant for the correctness of the necessary condition statement. There is only one combination of X and Y that can falsify the necessary condition hypothesis, namely the combination of the absence of the condition and the presence of the outcome. An important methodological implication, thus, follows from the logical characteristics of necessary conditions: *successful* cases, not failures provide information on its correctness. Similarly, also cases without the condition and not cases with the condition can falsify the necessary condition hypothesis.

Another misunderstanding is that conclusions regarding necessary conditions can be made from co-variational analyses such as regression analysis. Variables that in a regression analysis have a high explanatory power and significance are sometimes called "necessary" or "critical". Such variables are "critical" in the sense that they contribute considerably to the variance of the value of the outcome variable, but they are not "critical" in the sense that they are necessary for the occurrence of the outcome. Because a (multiple) regression analysis usually results in a large set of relevant independent variables (because the goal of such analysis usually is to maximize the explained variance in the value of the outcome variable), a manager might conclude that factors that contribute to the variance of the outcome factor needs to be addressed in order to achieve a higher likelihood of success. However, the necessary condition might even not be a member of this set. Managers who implement strategies based on regression results will not know which conditions are necessary to prevent guaranteed failure because the analysis does not provide information on conditions that are "necessary" or "critical".

It is not uncommon that necessary condition statements that have been correctly formulated are incorrectly quoted or re-formulated (and therefore obscured) in subsequent studies using co-variational language such as "more X results in more Y", rather than "X is necessary for Y", and that they are tested using conventional regression techniques. For example Leseure *et al.* (2004: 174) reformulated McLachlin's (1997) hypothesis "provision of training is a necessary condition for employee involvement" (which was confirmed in McLachlin's study) in co-variational language as "employee training is associated with employee involvement". Linderman *et al.* (2004: 397) formulate the following necessary condition hypothesis: "Quality management practices that foster contact and interactions between organizational members and customers *allow* knowledge to be created through socialization" (emphasis by us). Cousins and Menguc (2006: 617) quote this paper as follows: "[Our] research adds to the existing body of knowledge by demonstrating a linkage between socialization and operational performance, a link which has also been recently substantiated by Linderman *et al.* (2004) who found that socialization *had a positive effect on* the integration of quality management systems and knowledge creation processes" (emphasis by us). Cousins and Menguc tested the co-variational interpretation of the original hypothesis using conventional regression procedures.

Given the practical relevance of necessary conditions or critical success factors, it is crucial for the further development of our understanding of critical or necessary conditions that a methodology is available for building and testing necessary condition hypotheses. To address this, this paper proposes “Necessary Condition Analysis” (NCA), a methodology consisting of two stepwise approaches: one for identifying necessary conditions (when there are no a priori hypotheses), and one for testing necessary conditions (when hypotheses have been formulated).

4. NCA Part I: Building necessary condition hypotheses from cases

In this section we present a methodology for building necessary condition hypotheses from existing data sets from multiple cases or other sources. The data set should contain values of independent and dependent variables, for example organized as a data matrix in which each row corresponds to a case, and each column to a variable. The hypotheses to be built are formulated as an internally valid finding grounded in the data (“theory-building research”).

The approach is based on elements of currently established case study methodology (see Yin, 2009, Eisenhardt, 1989, and Voss *et al.*, 2002, in particular). This often used methodology for theory-building with cases starts with a *within-case analysis* in which each case is described in terms of the values of independent and dependent variables (e.g. found in documents, observed in meetings, or reported in interviews, etc.), followed by a *cross-case analysis* searching for similarities and differences between cases that can be described as hypotheses, and finalized with a *replication* performing an additional check on initial findings by replicating them in additional cases. An implicit assumption in the literature in which this approach is developed, discussed and illustrated is that theory consists of co-variational hypotheses of the form “more X results in more Y”. However, it is also possible to adopt a necessary condition perspective: NCA Part I for building necessary conditions provides this perspective and is based on a *cross-case analysis* consisting of the following three steps:

Step 1. Select cases on the basis of the presence of the outcome ("successful cases"). To build necessary conditions, we need to study *successful* cases. Hence, the first step in this approach is to select successful cases from the data matrix (i.e. cases with high values of the dependent variable).

Step 2. Formulate necessary condition hypotheses. In the second step the values of the independent variables are examined to see if the condition is present in all of the set of successful cases. A necessary condition hypothesis can be formulated if the condition (i.e. high values of an independent variable) is present in *all* successful cases. More than one necessary condition hypothesis could be formulated from a data set.

Step 3. Assess trivialness. A necessary condition is trivial if the condition is virtually always present. For example, the presence of gravity is a necessary condition for project success, but it is trivial because gravity is always present. A check on trivialness requires the identification of the existence of cases *without the necessary condition*. If such cases exist, the necessary condition is not trivial. *All* cases without the condition must not have the outcome (i.e., they must be failures). Note that identifying cases without the condition and ascertaining that they are failures is *not* the same as identifying failures and then ascertaining whether they have the condition. The latter procedure is wrong because having a necessary condition is not a guarantee of success and, thus, failure can occur in cases with the necessary condition.

If the hypothesis that was formulated in step 2 has survived step 3, it can be concluded that it is a non-trivial necessary condition that is supported by the evidence in this set of cases. If necessary, further replication studies may then be performed to verify the necessary condition in other cases (Hak and Dul, 2009b), see NCA Part II.

4.1. An example

We take an example of published OM research and show how this approach could be used to build necessary condition hypotheses. Verma and Sinha (2002) report a case study (with 11 cases) in which a theory is built on factors that influence project performance in high tech R&D environments. This study is one of the few examples in the OM literature in which case data on the independent and dependent variables are presented in the paper, so the reader can see how hypotheses are inferred from the data. To illustrate NCA methodology we demonstrate how necessary condition hypotheses can be built from these data. Table 2 is a consolidation of Tables 2-4 in the paper (Verma and Sinha 2002: 458-459).

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Insert Table 2 about here

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In each case the dependent variable (Y; project performance) was measured on a scale with a range from 0 to 1. Three levels of project performance were distinguished: Superior (1.00), Average (0.44-0.81) and Low (0.19-0.26). Nine independent variables X_i were coded into three categories or levels: Low, Medium, and High.

We will now demonstrate how necessary condition hypotheses can be built from these cases.

Step 1. If one is interested in conditions for superior project performance, only cases 1 and 2 in Verma and Sinha's set of cases are eligible.

Step 2. For building necessary condition hypotheses we need to identify the conditions that are present in *all* successful cases. This implies that we need to identify conditions that are present in both cases with superior project performance. We find six independent variables for which this applies (value of the independent variable is High). Hence we are able to formulate six necessary conditions hypotheses:

1. Superior project performance is only possible if Human resource availability and timeliness is high (X_1);
2. Superior project performance is only possible if Project manager's priority is high (X_2);
3. Superior project performance is only possible if Team member's priority is high (X_3);
4. Superior project performance is only possible if State of developed technology is high (X_4);
5. Superior project performance is only possible if Technology diffusion across projects is high (X_7);
6. Superior project performance is only possible if Business unit interest is high (X_8).

Step 3. To check for trivialness of each of these hypotheses we check whether there are cases without the condition. There are indeed for each condition at least three cases without the condition (i.e., with the value L or M for that variable). Because no superior performance occurs in any of these cases, we conclude that there is evidence in the data for six non trivial necessary condition hypotheses.

4.2. Discussion

It was not Verma and Sinha's aim to build necessary condition hypotheses. In their *cross-case analysis* they formulated eight co-variational hypotheses, e.g., "Business unit pull on a project [which is equal to "business unit interest"] is *positively associated* with project performance" (p. 461, emphasis by us). Although this co-variational hypothesis differs from our necessary condition formulation ("Superior project performance is only possible if Business unit interest is high"), it is also supported by the data, as there are three cases with low business unit interest (8, 10, and 11) that also have low project performance. Interestingly, in the description of their cross-case analysis Verma and Sinha also formulate a necessary condition statement about the role of business unit pull regarding superior project performance: “We infer that a business unit’s interest is only a necessary condition but not a sufficient condition for superior project performance” (p. 459). The evidence in Table 2 shows that Verma and Sinha’s statement is correct. It does not only confirm that business unit’s interest is a necessary condition for success (as we showed above), it also confirms that it is not a sufficient condition for superior project performance: Case 9 (with high business unit interest but low performance) contradicts the sufficient condition hypothesis. The fact that both the necessary condition hypothesis (“Superior project performance is only possible if Business unit interest is high”) and the co-variational hypothesis (“Business unit interest is positively associated with project performance”) are supported by the data illustrates that these are just two different ways of looking at the same data. However their differences should not be obscured and each should be evaluated on its own merits. For example, if a high level of business unit interest is a necessary condition for success (in the sense that a non-high level would *guarantee* non-high project performance), the managerial implications of the “positive association” type of proposition would severely understate the importance of business unit interest for successful performance. That is the reason why we recommend that researchers in theory-building studies always perform a Necessary Condition Analysis and build candidate necessary condition hypotheses.

5. NCA Part II: The methodology of testing necessary condition hypotheses with cases

We now examine how previously formulated necessary condition hypotheses can be tested. If hypotheses have been developed from a complete or partial extant data set this would involve replication in the rest of the data set, extending the data set or in a new data set. This is consistent with the replication logic used in theory building case research (Yin, 2009; Eisenhardt, 1989).

Necessary condition hypotheses are causal, and causal hypotheses can best be tested directly in experiments in which the cause is manipulated. A necessary condition hypothesis could be tested by an experiment in which (a) a successful case that has the condition is selected; (b) the condition is removed; and (c) it is observed whether its success disappears. For instance, we could test the hypothesis that superior project performance is only possible if business unit interest is high by (a) selecting a project with superior performance and with high business unit interest; (b) decrease or remove the business unit interest; and (c) observe whether performance deteriorates. However, as most such hypotheses concern important aspects of companies, processes, projects, or systems it may be impossible or too expensive to remove, merely for research purposes, a condition that is expected to be beneficial for the company. When such an experiment is not feasible, the researcher might search for ‘natural experiments’, i.e., cases in which the condition was removed for other reasons than for research. The hypothesis in such cases would be that its success had “left on horseback”. If an experiment is not feasible, and relevant ‘natural experiments’ are not available, a study of cases in their live context without manipulation is the only remaining research strategy for testing. This is the normal situation in everyday research practice.

Different elements of the methodology for testing necessary condition hypotheses with cases have been developed, discussed and applied in different disciplines, such as in political science (e.g. Dion, 1998; Braumoeller and Goertz, 2000), in formal logic (e.g. Fogelin and Sinnott-Armstrong, 2005), in a few papers in the management literature (e.g. McLachlin, 1997), and in social science research methodology (e.g. Dul and Hak 2008, Hak and Dul, 2009a,b). We integrate and expand on these separate developments and present a comprehensive stepwise approach for testing necessary condition hypotheses.

5.1. The methodology

The methodology for testing necessary condition hypotheses with cases entails the following seven steps; this is very similar to the methodology of any other type of theory testing study. The first steps deal with building a data set with cases that are relevant for testing necessary condition hypotheses. In a data set of N relevant cases, a necessary condition hypothesis can be evaluated N times (one test per case).

Step 1. Specify the domain in which the hypothesis is considered to be applicable. Any hypothesis is part of a theory with a specified domain. A hypothesis therefore should be accompanied with at a least an indication of the universe of cases (theoretical domain) in which it is supposed to be a valid claim. For instance, the hypothesis that "superior project performance is only possible if business unit interest is high" (identified in Verma and Sinha's data set) was built from data of eleven R&D projects in one Fortune 500 high technology manufacturing firm. When the hypothesis is formulated as the result of a study of these eleven R&D projects, it must be specified whether it could be assumed that this hypothesis is true for all R&D projects in all companies in the world, or only for projects in specific types of industry, or only in very large firms, or only some parts of the world, etc. This is important because the test of the hypothesis should be conducted in cases that are members of the specified theoretical domain.

Step 2. Select cases from the theoretical domain. The necessary condition is defined for each single case by the combination: condition X is absent, outcome Y is present not being possible (see Figure 1). It is possible to select a single case for a single test, or to select a set of cases for repeated tests. Because these cases should allow for testing the impossibility of (X=0;Y=1), cases are needed in which the dependent variable is present ("row strategy" with "successful cases";Y=1) in order to test whether indeed the condition is not absent (not X=0), or cases in which the independent variable is absent ("column strategy"; X=0) in order to test whether the outcome is not present (not Y=1). Note that it makes no sense for a test to select cases in which the outcome is absent (Y=0), because the necessary condition hypothesis does not imply any condition for the absence of the outcome. It is equally not relevant for a test to select cases in which the condition is present (X=1) because the necessary condition hypothesis does not exclude the possibility that the outcome is absent in such cases. For example, if we would use the set of 11 cases from Verma and Sinha (2002) presented in Table 2 to test the necessary condition on business unit involvement, only six cases would be relevant for the test (cases 1 and 2 with the outcome present, and cases 2, 8,9,10 and 11 with the condition absent). The other five cases are irrelevant for the test.

When a set of relevant cases is selected for testing a necessary condition this set preferably contains not only cases in which the outcome is present, but also cases in which the condition is absent in order to be able to test the non-trivialness of the necessary condition. If a set of cases as a whole is selected for testing a necessary condition, it needs to be selected from a specified population within the domain, because these cases must be comparable in relevant respects.

Step 3. Specify the expectation for the selected cases. The hypothesis is that there are no cases in which the condition X is absent, and the outcome Y is present (X=0;Y=1), or in other words that the upper-left cell in Figure 1 is empty. This means that in a case in which the outcome Y is present (Y=1), the hypothesis is “X is present” (X=1). In a case in which the condition X is absent (X=0), the hypothesis is “Y is absent” (Y=0).

Step 4. Present scores. Scores of X (present or absent) and Y (present or absent) can come from an existing database or from new measurements. The scores can be presented in a 2x2 matrix as in Figure 1.

Step 5. Perform the test. Testing consists of identifying the number of cases without X and that have Y. The test consists here of comparing the actual number of cases in the upper-left cell with the expectation (N=0).

Step 6. Formulate the test result. The test result is either a *disconfirmation* of the expectation or a *confirmation*. The expectation is disconfirmed if the observed number of cases in the cell (X=0;Y=1) is 1 or more, and the expectation is confirmed if it is zero.

Step 7. Formulate the implications of the test result for the theory. The implication of the test result for the theory depends on the outcome of step 6. A confirmation of the hypothesis supports the necessary condition theory. Further replication studies may be needed for more definitive conclusions (Hak and Dul, 2009b).

A disconfirmation of the hypothesis is generally more informative about the correctness of a theory than a confirmation. The specific cases that disconfirm the hypothesis, often referred to as "counterexamples", should be carefully evaluated regarding whether they, for instance, indicate special causal mechanisms, suggest problems in conceptualization or measurement of X or Y, or point to limits to the domain in which the hypothesis applies. They may give rise to reformulating the hypothesis or the theoretical domain to which the hypothesis applies, and may give direction to further testing and replication.

The methodology for testing necessary condition hypotheses with single cases is based on the non-probabilistic nature of the claim that the absence of X results in the absence of Y. If this is read as meaning "often results" or "almost always results" rather than as "always results", then it is possible to treat a small number of disconfirmations (or "counterexamples") in a large series of tests as inconsequential for the overall correctness of the necessary condition hypothesis in the specified domain (Dion, 1998; Ragin, 2000) . One could, for instance, specify a maximum proportion of counterexamples (say 5%, i.e. not more than one counterexample in 20 cases). For example, if one would test the necessary condition hypothesis: "Superior project performance is only possible if business unit involvement is high" using Verma and Sinha's data set (Table 2), then there are five confirmations (cases 1,8,9,10 and 11) and one disconfirmation (case 2). The proportion of one disconfirmation out of six relevant cases (17%) does not pass the 5% criterion; hence in this example the probabilistic version of the necessary condition hypothesis is also disconfirmed. Note that a probabilistic version of a necessary condition hypothesis does not turn it into a co-variational one. It still is a hypothesis about a necessary condition, though with some exceptions. In a data set of N relevant cases, a necessary condition hypothesis can be tested N times (one test per case), but a co-variational hypothesis can be tested only once (in the "sample").

5.2. Example

Possibly the only published example of a study in OM in which already formulated necessary condition hypotheses are tested is the study by McLachlin (1997). We will use this study as an illustration of the methodology for testing necessary condition hypotheses with cases.

Step 1. McLachlin (1997) formulated 20 necessary condition hypotheses, composed of six conditions (provision of workforce security, promotion of employee responsibility, provision of training, promotion of teamwork, use of team performance measures, demonstration of visible commitment) and three outcomes (employee involvement, Just-In-Time (JIT) flow and JIT quality). Also employee involvement was considered a necessary condition for JIT-flow and JIT-quality. These hypotheses are listed in Table 3.

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Insert Table 3 about here

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The domain in which these hypotheses are supposed to apply is not explicitly specified, but it probably consists of all companies that implement JIT.

Step 2. Six cases (named A-F) are chosen from the domain. No selection criteria were applied regarding the presence of the outcome, or the absence of the condition.

Step 3. Although not explicitly stated, it is clear from the analysis as presented by McLachlin that the "expectation" is that, for each of the 20 hypotheses, no case will be found in which the condition X is absent and the outcome Y is present.

Step 4. The variables were measured on a 7 point scale. The scores that were obtained were dichotomized into low scores (L) and high scores (H). Scores on the midpoint of the scale were coded as "Neutral". The resulting data matrix is shown in Table 4.

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Insert Table 4 about here

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Step 5. Although not explicitly stated we conclude from McLachlin's analysis that for each test of a hypothesis, cases with a neutral value for the condition or a neutral value for the outcome were excluded. For the remaining cases it was evaluated whether the combination of values (X=L and Y=H) did not occur according to the expectation. For example, Figure 2 (left) shows the test of the hypothesis; "provision of workforce security is a necessary condition for employee involvement", in which there are four cases (B, C, D, F) that show this unexpected combination. Another example (Figure 2, right) shows the test of the hypothesis "provision of employee responsibility is a necessary condition for employee involvement", in which there were no cases with this combination.

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Insert Figure 2 about here

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Step 6. McLachlin considers a hypothesis to be 'confirmed' if it is 'not disconfirmed', i.e. if (and only if) there is no counterexample in the set of selected cases. In the first example (Figure 2, left), the hypothesis is disconfirmed because there are four counterexamples. In the other example (Figure 2. right), the hypothesis is confirmed because there is no counterexample.

Step 7. McLachlin claims that these results can be generalized to plants that are similar to the plants (in Canada) that were studied (p. 285). McLachlin did not discuss in what type of cases his findings (both confirmations and disconfirmations) could be replicated.

5.3. Discussion

McLachlin's study is an exemplary and convincing application of a methodology that is appropriate for testing necessary condition hypotheses. However, its value has not always been acknowledged. For example, McLachlin's evidence that teamwork is a necessary condition for JIT flow and JIT quality has been called "anecdotes" (Pagell and LePine, 2002:620), and his finding that "provision of training is a necessary condition for employee involvement" has been reformulated in co-variational language as "employee training *is associated with* employee involvement" (Leseure *et al.*, 2004: 174, emphasis by us). It appears that the fundamental difference between a necessary condition hypothesis and a co-variational hypothesis, and the possibility to test necessary condition hypotheses with cases, are not recognized.

6. Necessary condition hypotheses with *continuous variables*

Until now we have presumed that X and Y are discrete variables. We discussed examples in which the necessary condition X had a discrete value (e.g. "Present" and "Absent", or "Low", "Medium" and "High"), and the outcome also had discrete values ("Present" and "Absent"). Data for such variables can be presented in 2x2 tables (such as in Figures 1 and 2) or in extensions of such tables with more rows or columns. Figure 3 (left) is an example of a 3x3 table presenting the data from Verma and Sinha pertaining to one of the necessary condition hypotheses that we have inferred from their data, namely “Superior project performance is only possible if Human resource availability and timeliness is high”. Verma and Sinha define three levels of Project performance: Superior, Average and Low and accordingly the project performance scores have been categorized into three discrete values.

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Insert Figure 3 about here

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As in a 2x2 table, the necessary condition is defined by an empty space in the upper-left corner.

However, the original data for Project performance were not discrete but continuous on a scale from 0 to 1. Figure 3 (right) is a scatter plot of the eleven cases according to their performance scores on this scale. The necessary condition that we have inferred from Verma and Sinha’s data is characterized again by an empty space in the upper-left corner.

One step further, both the condition and the outcome are continuous variables. Figure 4 (left) is a general plot (with arbitrary data) showing a continuous necessary condition.

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Insert Figure 4 about here

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Again, the necessary condition is characterized by an empty space at the upper left corner. This empty space indicates that for a range of lower values of the X it is not possible to have a higher value of Y. In other words higher values of Y are only possible if there are higher values of X. A certain value of Y is only possible if a certain “condition” (i.e., a minimum level of X) is present. This minimum level of X that is necessary for a given Y does not *guarantee* that this level of Y is achieved (i.e. it is not sufficient). The range of combinations of minimum levels of X for a given Y can be presented by a boundary line or "ceiling", such as the solid line in Figure 4 (right). This line specifies, for each possible value of X, the maximum value of Y. A given value of X (X_c), thus, specifies a specific ceiling Y_c. X_c does not guarantee that Y_c is reached (X_c is not sufficient for Y_c), but it is guaranteed that a *higher* value than Y_c is *not* reached (so there are no observations above the ceiling).

The ceiling is not necessarily a straight line, nor a continuously increasing line, nor must it always cross the X-axis or the Y-axis. A discussion on defining ceiling lines is beyond the scope of this paper (see Goertz *et al.*, 2008), but whatever the precise shape of the line, it will be a boundary line between a space with cases and a space without cases (in the definition of a continuous necessary condition). With the convention that X (the condition) and Y (the outcome) are on the horizontal and vertical axis, respectively, the empty space will be located in the upper-left space of the plot, typically resulting in a triangular shape of the latter. The ceiling line is by definition a line at the boundary of the scatter plot.

6.1. Ceiling versus regression

A line "through the middle" of the data is by definition not an appropriate specification of a ceiling and can, therefore, not be used for building or testing a continuous necessary condition. Figure 4 (right) shows an example of such "line thought the middle": the OLS regression line (dashed line) with a slope of 0.32 ($R^2 = 0.103$). A ceiling line and a regression line represent two fundamentally different phenomena: the ceiling line represents a necessary condition hypothesis (X is necessary for Y), whereas the regression line represents a co-variational hypothesis (X affects Y). They refer to different causal mechanisms and, therefore, yield results that cannot contradict (or confirm) each other. It is an empirical matter whether both a necessary condition hypothesis and a co-variational hypothesis between the independent and the dependent variable can be inferred from the data, or none of them, or only one of them.

A “triangular” data set as in Figure 4 is usually characterized by heteroscedasticity (with larger variances of Y for higher values of X) and low correlation. Many researchers consider heteroscedasticity as a problem, and variance stabilizing transformation methods are used to eliminate its effects. Instead, we suggest that heteroscedasticity can indicate that there is a necessary condition phenomenon in the data set, which could be described by a ceiling line. An important implication is that researchers should examine scatter plots of the core dependent and independent variables to search for empty spaces, in data sets with and without positive regression.

6.2. Building and testing a continuous necessary condition

The main difference between the methodology of building a *discrete* necessary condition hypothesis (as shown above) and the methodology of indentifying a *continuous* necessary condition hypothesis, is that we depart from a data set with continuous values rather than discrete values, i.e., from a (bivariate or multivariate) scatter plot rather than from a data matrix. Basically, the proposed steps condense to building and testing empty spaces in the upper-left corner of the scatter plot. Criteria for evaluating whether the empty space is large enough for justifying the formulation of a necessary condition hypothesis are arbitrary in principle (for some rules see Goertz *et al*., 2008). Again, one may wish to allow for a certain proportion (e.g. 5%) of counterexamples in the “empty” space.

We have not been able to find an example of an empirical investigation of a continuous necessary condition hypothesis in the OM literature. We assume that the reason for this absence is, as discussed above, that researchers in OM have focused on co-variational hypotheses, and have not considered the possibility of necessary condition hypotheses. In rare situations that such possibility is considered, only the dichotomous version is regarded, as most people associate necessary conditions with a condition being absent or present. If journals would publish scatterplots of data, this would assist researchers in indentifying data that fit (continuous) necessary conditions hypotheses.

7. Conclusions

In this paper we have discussed the necessary condition hypothesis (“Y only if X”), which is fundamentally different from the common type of hypothesis that expresses a co-variational relationship (“more X gives more Y”). We showed that there are many examples of necessary condition hypotheses in OM, but that the value, the special characteristics, and the special methodologies for building and testing such hypotheses are not always recognized. We distinguished between discrete necessary conditions (“X must be present to have Y”), and continuous necessary conditions (“A given level of X must be present to have a given level of Y”). We presented a practical methodology for OM researchers (Necessary Condition Analysis, NCA) consisting of two stepwise approaches, one to build and the other to test necessary condition hypotheses in empirical data sets.

Based on our findings and analysis we formulate seven recommendations for OM researchers:

1. Recognize that co-variational relations, and necessary conditions are equally valid but fundamentally different;
2. Recognize that an empirical data set may not only contain co-variational relationships, but also necessary conditions. It is also possible that data sets without co-variational relationships do contain necessary conditions;
3. Publish the scores of the most important independent and dependent variables in data matrices (for discrete variables) or scatter plots (for continuous variables), to allow for inspection of the possibility of necessary conditions in the data.

4. Do not formulate results of a co-variational analysis (e.g. regression) in terms of necessary conditions (e.g. “X is necessary for Y”); and do not formulate results of a Necessary Condition Analysis (NCA) in co-variational terms (e.g. “X affects Y”);
5. Use a methodology like NCA for building and testing necessary condition hypotheses;
6. For building or testing necessary conditions, cases.with the outcome (“successes”) or cases without the condition must be selected for such an analysis. Cases without the outcome (“failures”), or cases with the necessary condition are not appropriate for this purpose.
7. Recognize that the managerial relevance of a necessary condition might be stronger than that of a co-variational relationship. Not implementing the necessary condition *guarantees failure*, whereas not implementing the co-variational variable only *reduces success*. Therefore, we recommend that researchers *always* search for necessary conditions in their data sets.

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Table 1. Examples of alternative formulations for “X is a necessary condition for Y”.

X is needed for Y
X is critical for Y
X is crucial for Y
X is essential for Y
X is indispensable for Y
X is a prerequisite for Y
X is a requirement for Y
X is a pre-condition for Y
X allows Y
There must be X to have Y
Y requires X
Y exists only if X is present
Y is only possible if X is present
Y becomes possible with X
Y does not exist without X
If there is Y then there is X
Without X there cannot be Y
If there is no X there cannot be Y

Table 2. Data matrix for building necessary condition hypotheses (from Verma and Sinha , 2002).

Case	X_1 Human resource availability and timeliness	X_2 Project manager's priority	X_3 Team member's priority	X_4 State of developed technology	X_5 Existing knowledge of technology	X_6 Modularity in design	X_7 Technology diffusion across projects	X_8 Business unit interest	X_9 Business unit involvement	Y Project performance	Classification of Project performance
1	H	H	H	H	H	H	H	H	H	1.00	"Superior"
2	H	H	H	H	M	L	H	H	L	1.00	
3	H	H	H	H	H	H	H	H	H	0.81	"Average"
4	M	H	M	H	H	H	H	H	H	0.68	
5	M	H	H	H	M	H	M	H	H	0.55	
6	M	H	M	H	M	L	M	H	H	0.44	
7	M	H	M	H	M	L	M	H	H	0.44	
8	L	L	L	H	M	H	M	L	L	0.26	"Low"
9	L	M	M	M	H	M	H	H	L	0.26	
10	L	M	M	M	H	M	H	L	L	0.22	
11	H	L	L	M	H	H	H	L	L	0.19	

H=High; M=Medium/Average; L=Low

Table 3. Necessary condition hypotheses tested by McLachlin (1997).

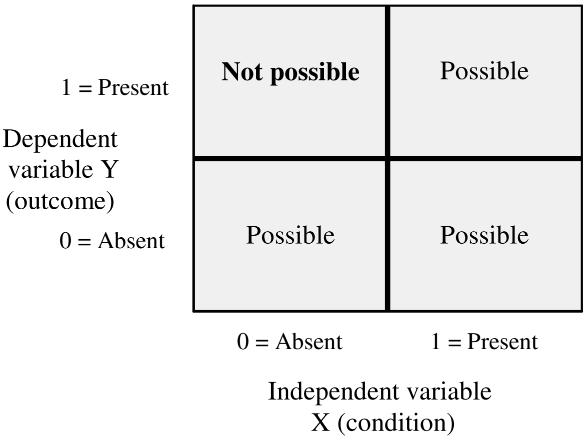
1	Provision of workforce security is a necessary condition for employee involvement
2	Promotion of employee responsibility is a necessary condition for employee involvement
3	Provision of training is a necessary condition for employee involvement
4	Promotion of teamwork is a necessary condition for employee involvement
5	The use of group performance measures is a necessary condition for employee involvement
6	Demonstration of visible commitment is a necessary condition for employee involvement
7	Provision of workforce security is a necessary condition for JIT flow
8	Promotion of employee responsibility is a necessary condition for JIT flow
9	Provision of training is a necessary condition for JIT flow
10	Promotion of teamwork is a necessary condition for JIT flow
11	The use of group performance measures is a necessary condition for JIT flow
12	Demonstration of visible commitment is a necessary condition for JIT flow
13	Provision of workforce security is a necessary condition for JIT quality
14	Promotion of employee responsibility is a necessary condition for JIT quality
15	Provision of training is a necessary condition for JIT quality
16	Promotion of teamwork is a necessary condition for JIT quality
17	The use of group performance measures is a necessary condition for JIT quality
18	Demonstration of visible commitment is a necessary condition for JIT quality
19	Employee involvement is a necessary condition for JIT flow
20	Employee involvement is a necessary condition for JIT quality

Table 4. Data matrix for testing necessary condition hypotheses (Adapted from McLachlin, 1997).

Case	Provide employment security	Promote employee responsibility	Provide training	Promote teamwork	Use group performance measures	Demonstrate visible commitment	Employee involvement	JIT flow	JIT quality
A	L	L	L	L	L	L	L	L	L
B	L	H	H	H	-	H	H	H	H
C	L	H	H	H	H	H	H	H	H
D	L	H	-	-	L	H	H	H	H
E	L	L	-	L	L	-	L	-	-
F	L	H	H	-	L	-	H	-	-

Figure 1 The 2x2 matrix representing the necessary condition.

Empirical combinations of scores for the variables X and Y when X is a necessary condition for Y.



	0 = Absent	1 = Present
1 = Present	**Not possible**	Possible
0 = Absent	Possible	Possible

Figure 2. Necessary condition test with 6 cases (A-E).

Left: for the hypothesis that “provision of workforce security is a necessary condition for employee involvement” (disconfirmed).

Right: for the hypothesis that “provision of employee responsibility is a necessary condition for employee involvement” (confirmed).

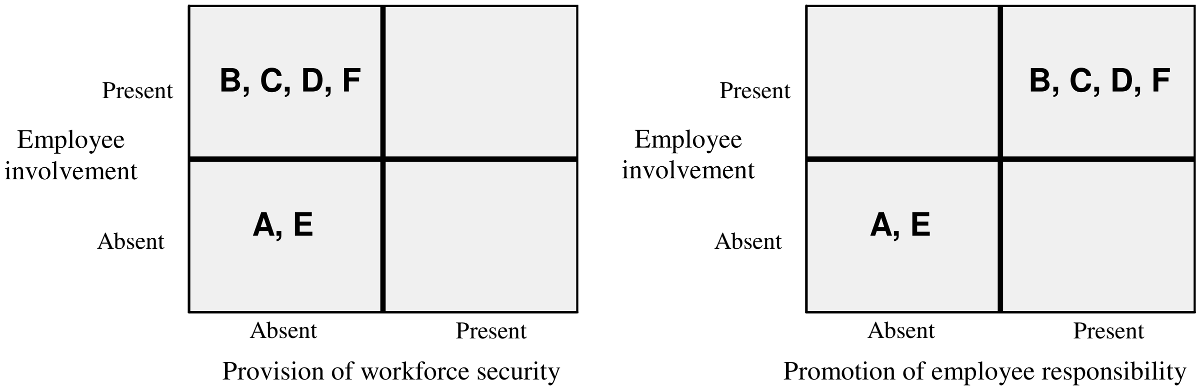
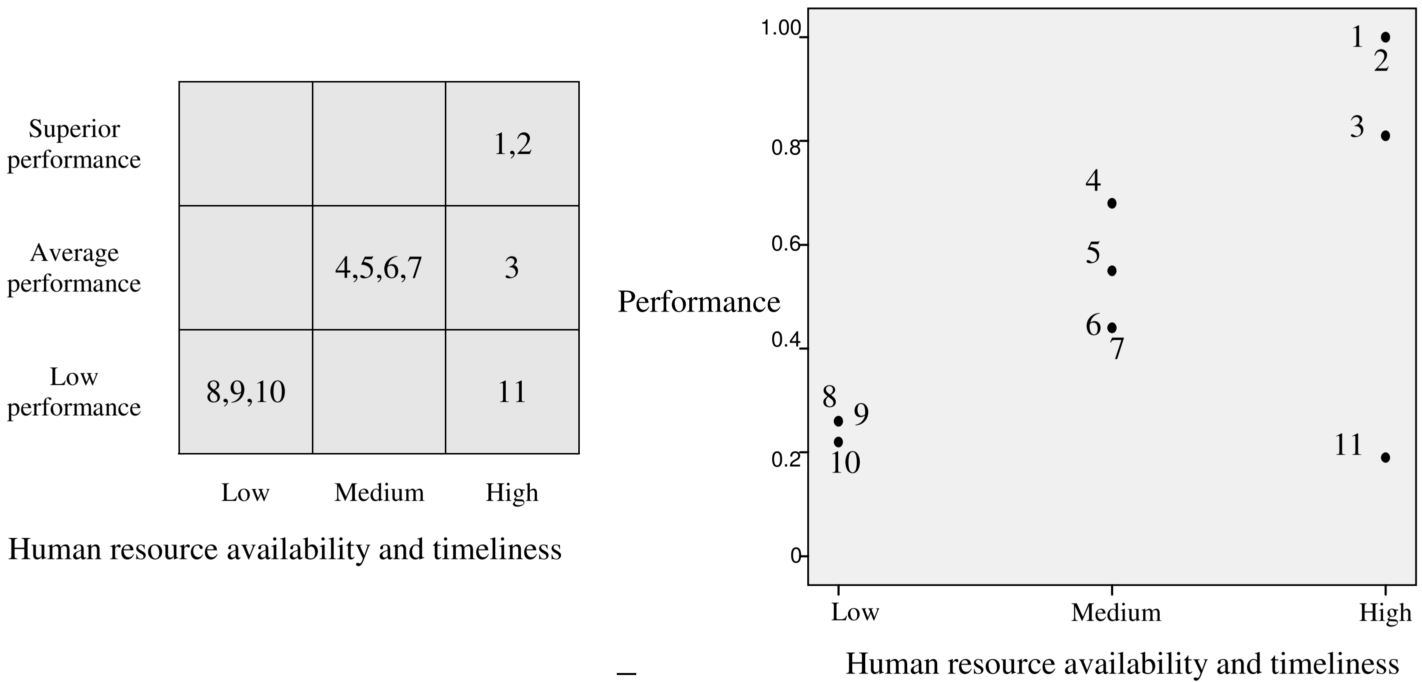


Figure 3. Verma and Sinha’s eleven cases according to their scores for the variables Human resource availability and timeliness (X) and Project performance (Y). Numbers refer to case numbers.

Left: 3x3 matrix with discrete variables.



Superior performance			1,2
Average performance		4,5,6,7	3
Low performance	8,9,10		11
	Low	Medium	High

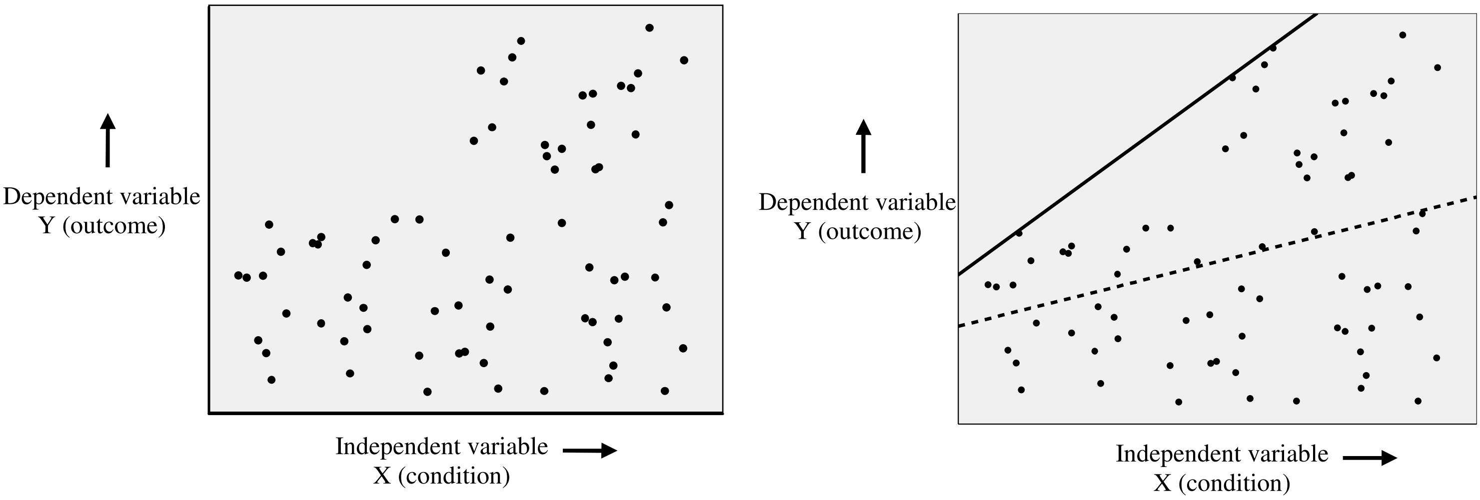
Human resource availability and timeliness

Right: Scatter plot with continuous performance scale.

Figure 4. Scatter plot with a distribution of cases indicating a continuous necessary condition.

Left: Empty space in the upper left corner

Right: solid line: boundary line between the area with and without cases (ceiling); dashed line: regression line through the middle of the cases



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