

Iterative triangulation: a theory development process using existing case studies

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Abstract

To cope with the growing frequency and magnitude of changes in technology and managerial methods, Operations Management (OM) researchers have been calling for greater employment of field-based research methods. A notable example is grounded theory development using original case studies. Based on in-depth examinations of ‘real-world’ operations conditions, case studies potentially improve the relevance and workability of resulting OM theory. However, developing original case studies requires considerable time and expense, straining research resources and often limiting the number of operations settings that can be studied and compared during induction. Existing case studies offer a potentially effective and efficient means for comparing complex and disparate operations settings. This paper proposes a novel theory development process, termed iterative triangulation, for tapping this potential. Iterative triangulation employs systematic iterations between literature review, case evidence, and intuition. The process enhances theory creativity, utility, and validity by deliberately increasing the diversity and quantity of literature reviewed, of cases found, of conjectures examined, and of conjecture selection criteria. Comparing and contrasting emerging constructs and theory across case settings refines conceptual definitions and strengthens internal validity, enhancing testability of resulting theory. A study of advanced manufacturing technology design illustrates the method. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Ideally, Operations Management (OM) theories should guide empirical research by providing a greater understanding of the many interrelated variables influencing operations performance in real-world settings (McCutcheon and Meredith, 1993). An effective theory consists of two elements that facilitate and motivate future OM research. First, refined core constructs articulate conceptual distinctions and enhance validity and reliability (Flynn et al., 1994). Second, an encompassing theoretical framework clarifies the nature of complex and dynamic construct interrelationships (White, 1996).

The rapid evolution of operations technologies and managerial methods, however, poses a significant challenge to OM theorists. Meeting this challenge may require moving beyond the deductive, quantitative tools that dominate OM research to incorporate alternate means geared toward induction and description (Swamidass, 1991). To grasp the nature and impact of these dramatic changes, theory development methods should enable comparative analyses of complex operations settings and foster opportunities to question widely held OM assumptions. McCutcheon and Meredith (1993) proposed that case studies provide an excellent means to help fill OM’s theoretical needs. However, they also noted

that the considerable time and financial expenses necessary to conduct original case studies make grounded theory development relatively inefficient.

This paper proposes a novel inductive approach, termed *iterative triangulation*, that contributes to existing OM methodologies a potentially effective and efficient means of theory development. Iterative triangulation employs systematic iterations between literature review, case evidence, and intuition. This method is particularly distinctive in its use of existing case studies. Certainly, theorists have examined existing cases when developing and refining theory. For example, Mintzberg et al. (1976) developed a theory of unstructured strategic decision making by analyzing case studies written by their MBA students. Kelley (1986) employed existing cases to refine a contingency theory of the deskilling effects of programmable automation. She analyzed her own case study and reinterpreted others' cases using her constructs, often arriving at different conclusions from a case than did its authors. Unfortunately, these and related studies do not specify the inductive procedures used to examine existing cases. With iterative triangulation, a rigorous process and explicit techniques for comparing diverse case settings and incorporating varied research perspectives aid development of creative, useful, and valid OM theory.

Sections 2–4 describe the theory development guidelines, propose the OM role, and detail the methodological process of iterative triangulation. First, outlining general theory development guidelines clarifies the objectives and methodological bases of iterative triangulation. Second, a discussion of its advantages, limitations, and appropriate uses suggests the place of iterative triangulation among extant OM research methods. Third, detailed description of the methodological process aids understanding and potential future use of iterative triangulation. A study of advanced manufacturing technology (AMT) design illustrates the method.

2. Guidelines for theory development

Prior to beginning a theory development project, theorists should explicitly state (1) their criteria for a quality theory and (2) their methods for developing quality theory (Bourgeois, 1979; Eisenhardt, 1989).

While theorists disagree as to the weight of different theoretical criteria, a theory's quality is predominantly determined by the degree to which it is creative, useful, and 'scientific'. Creative theories provide novel insights that challenge preexisting assumptions (Weick, 1989). Utility depends upon a theory's potential to advance a body of literature in meaningful ways (e.g., by linking fragmented research or providing a foundation for future research) (Mintzberg, 1979). 'Scientific' theories are assembled from valid, operationalizable constructs related in a logically consistent manner, enabling empirical testing and possible refutation (McCutcheon and Meredith, 1993). Unfortunately, theorists' myopic perspectives (Larsson, 1993) and poor information processing capabilities (Eisenhardt, 1989) often hamper theory development. Developing quality theory requires methods that broaden normal boundaries of rationality, enabling theorists to 'think better' (Weick, 1989).

Literature reviews, data, and intuition form the bases of most theory development methods. Yet, focusing predominantly on one base may impede theoretical quality. Building theory largely on literature review may stifle creativity (Bourgeois, 1979). Reviews often are restricted by sparse, contradictory, or ambiguous literature and by premature exclusion of studies because of their misfit with the theorist's dominant perspective or discipline (Larsson, 1993). Grounding theory on data requires considerable primary data, usually in the form of original case studies (Eisenhardt, 1989; McCutcheon and Meredith, 1993). However, the expense of developing original cases typically results in small sample sizes that inhibit the diversity of phenomena examined, often producing idiosyncratic theories (Larsson, 1993). Developing theory based predominantly on intuition (i.e., the theorists' assumptions, judgment, and past experiences) requires entering with a hypothetical 'blank slate'. This method potentially limits theory utility, as it risks rediscovering existing theories or developing a completely unique theory that complicates research comparisons (Bourgeois, 1979).

To foster development of higher quality theories, some theorists have prescribed using systematic processes that integrate the three bases (e.g., Bourgeois, 1979; Mintzberg, 1979; Weick, 1989). Iterative triangulation follows this prescription. The basic proce-

dures consist of selecting a set of relevant, usable cases, searching for patterns among those cases, and iterating between case evidence, reviewed literature, and intuition to extend and link conjectures into a cohesive theory. Methodical iterations increase the potential of convergence on a quality theory. The process may enhance theoretical utility by developing linkages to a wider range of existing perspectives, research, and OM contexts. Juxtaposing highly varied case accounts may foster creative leaps in theory development, requiring the theorists to re-frame their preexisting assumptions. In addition, systematic iterations that develop a chain of triangulated evidence may enhance the scientific value of the resulting constructs and theory by improving their validity, reliability, and logical consistency.

When constructing the iterative triangulation process, I incorporated relevant insights from varied research streams. General theory development literature provided a valuable understanding of the theory development process, particularly as it pertains to the use of literature reviews and of the theorists' own intuition, judgment, and mental experiments (e.g., Bourgeois, 1979; Mintzberg, 1979; Weick, 1989). Case survey methodology, a theory testing approach using existing case studies, offered insight into the location, selection, and coding of cases (e.g., Bullock and Tubbs, 1987; Larsson, 1993; Lucas, 1974). Lastly, grounded theory development research, while employing original case studies, suggested specific inductive techniques for theoretically sampling and analyzing cases (e.g., Eisenhardt, 1989; McCutcheon and Meredith, 1993; Parkhe, 1993; Thomas, 1994; Yin, 1984).

3. Iterative triangulation

Inductive case research typically employs triangulation, using multiple data sources and analytical techniques to improve representational accuracy of resulting theory (McCutcheon and Meredith, 1993). Iterative triangulation expands the traditional notion of triangulation, utilizing existing case studies to enhance representational diversity. Employing numerous inductive techniques, comparing conjectures to reviewed literature, and conducting mental experiments aids examination of varied research sites,

methodologies, and theoretical perspectives across case studies.

3.1. Advantages

Iterative triangulation can be an efficient and effective means of theory development. Analyzing existing case studies taps an often abundant source of field-based information, while conserving valuable resources that would have been needed to conduct multiple, original case studies. Ideally, cases can provide thorough description of constructs, construct interrelationships, organizational contexts, and processes from multiple stakeholder perspectives, data collection methods, and levels of analysis (Yin, 1984). The potential depth and diversity of descriptions of 'real-world' operations settings may improve the relevance, utility, and workability of resulting theory for managers.

Iterative triangulation also aids development of conceptual and theoretical foundations for future OM research. Conceptually, comparing and contrasting constructs across case settings refines construct definitions. In a sense, constructs are operationalized during iterations to enable comparisons between cases, enhancing testability of resulting theory. Conceptual distinction and refinement is particularly important for core OM constructs that are fuzzy and multidimensional, such as quality (Flynn et al., 1994), manufacturing flexibility (Gerwin, 1993), and operational infrastructure (Maffei and Meredith, 1995).

As many OM areas require understanding complex human, technical, and organizational systems and their dynamic interrelationships (McCutcheon and Meredith, 1993), iterative triangulation may help researchers develop encompassing theoretical frameworks. Searching for patterns across diverse case contexts provides a distinct opportunity to construct novel hypotheses and comprehensive theory. The theorist must seek imaginative means to link purposefully varied (often seemingly contradictory) case situations. In addition, the theorist must consider different case authors' perspectives, potentially reducing researcher bias (Larsson, 1993). The descriptive depth and longitudinal focus of many case studies may facilitate researchers' understanding of causality and complex interrelationships, invaluable, for instance, when examining technology implemen-

tation (Maffei and Meredith, 1995) and interwoven manufacturing capabilities (White, 1996).

3.2. Limitations

By nature, theory development is a less-than-ideal exercise (Weick, 1989). The predominant limitations of iterative triangulation revolve around its use of existing cases. First, the quantity of available cases restricts this methodology. While McCutcheon and Meredith (1993) found only a scant number of cases in mainstream OM publications, their review focused on “articles in OM-related journals and not OM case studies in the literature in general” (p. 249). A surprising number of cases often exist in alternate sources, ranging from research books to teaching cases to dissertations within OM and across related disciplines, including engineering, sociology, economics, strategic management, and organization theory. Using multiple case sources and search strategies can increase case quantity and diversity and lessen case selection bias (Larsson, 1993).

Second, existing cases often provide incomplete information. Depending on the comprehensiveness of the emerging theory (e.g., number of constructs and interrelationships examined) few if any cases will cover the entire theory. Hence, iterative triangulation requires examining many diverse cases and piecing together theory. This process results in a theory bound together by existing literature, intuition, and judgement with pieces grounded in actual data. Surveying case authors provides a valuable means to fill gaps in case data and to evaluate the emerging theory.

Third, even when a case covers all constructs of interest, case write-ups do not include field notes. Some case authors focus description on “research sites and data collection methods but give little space to discussion of analysis and a huge chasm often separates data from conclusions” (p. 539 of Eisenhardt, 1989). Therefore, iterative triangulation develops theory using interpretations of interpretations. While many theorists will understandably favor greater closeness to primary data, iterative triangulation provides an efficient alternative to study many, diverse organizational contexts.

Stating the limitations of iterative triangulation avoids stretching the methodological advantages and

resulting theoretical contributions beyond reason. Resulting theory should not be presented as ‘proofs’. Iterative triangulation focuses on specific phenomena, enabling development of midrange theories that provide a foundation for future OM research. This method is not a substitute for getting into the real world, but may help researchers know what to look for when they enter the field. By aiding the development and refinement of constructs and a theoretical framework, iterative triangulation may serve as the first step in more intensive research projects, guiding the design of empirical, field-based research.

3.3. Appropriate uses

Iterative triangulation is most appropriate for examining substantive OM topics that are relatively underdeveloped. More specifically, this method may be particularly applicable when four conditions exist that maximize its advantages, while downplaying its limitations. First, the literature must contain sufficient case study work. Second, when existing literature employs an array of conceptualizations of the core construct(s) and/or requires conceptual redefinition, cases enable examination of many, different forms of the construct, facilitating conceptual development. Third, as some cases describe complex interrelationships, iterative triangulation may aid theorists when their goal is integration of previously fragmented research (i.e., when extant studies focus on one or two relationships at a time). The longitudinal nature of some cases may also assist theorists wishing to examine the dynamic nature of interrelationships or processes. Finally, when existing literature contains contradictory theory and evidence and spans theoretical perspectives and academic disciplines, iterative triangulation provides a systematic method to spur creativity in the search for connections.

3.4. Illustrative study

A study of AMT design (termed the illustrative study) exemplifies the application of iterative triangulation. AMT is a system of tasks and computerized machinery designed to execute and control the production process. While sophisticated computerization has dramatically increased the flexibility and diversity of AMT designs, it has also complicated the

design process considerably. AMT design failures, ranging from process improvements that fall short of expectations to abandonment of AMT after considerable investment, appear to be the norm rather than the exception (Scarbrough and Corbett, 1992). These dramatic technological changes and corresponding design difficulties signify the need for greater understanding of the nature of AMT designs and the processes within which they develop. Hence, the purposes of this study were two-fold: (1) to develop an effective AMT design construct (capable of differentiating between flexible, computerized technology designs), and (2) to place that construct within a nomenclological net (a comprehensive framework illustrating the nature of AMT design's interrelationships with several key constructs during the design process).

According to the four conditions for appropriateness described in the previous section, iterative triangulation offered an exceptional opportunity to achieve the research objectives. First, the development of AMT spurred a dramatic increase in case study research of technology (Davis and Taylor, 1976). In fact, recently Dean et al. (1992) called case studies the “predominant mode of inquiry into the effects of new technology” (p. 204). Second, technology literature contains a plethora of technology constructs, many of which are incapable of discriminating between computerized AMT designs (Dean et al., 1992; Scarbrough and Corbett, 1992). Iterative triangulation may aid reconceptualization as many existing cases describe technology in enough depth that “even though we as readers may not agree with the designations, we at least have sufficient information about the technology and can label it ourselves to suit our own classifications” (Davis and Taylor, 1976, p. 391). Third, most studies have focused narrowly on AMT design's relationship to one or two organizational phenomena during the design process (Scarbrough and Corbett, 1992). Case studies may aid development of a comprehensive theory of AMT design, because an average case describes some or all components of the AMT design process, including: the drivers of design change (e.g., production bottlenecks), influential factors of design choice (e.g., strategic focus), elements of design implementation (e.g., simultaneous changes in structure and/or human resource management practices), and subse-

quent impacts (e.g., system performance). Finally, case authors have examined manufacturing sites across the globe and from numerous perspectives (e.g., OM, industrial and human factors engineering, technology and innovation management, work humanization/sociotechnical, and labor process theories). This diversity may increase the generalizability of the developed constructs and theory to better guide AMT designers and facilitate research comparisons.

4. Methodological process of iterative triangulation

Iterative triangulation unfolds in four phases (see Fig. 1). This methodological process follows many prescriptions of Weick (1989) for developing theory using ‘disciplined imagination’. Systematic procedures enhance theory quality by deliberately increasing the diversity and quantity of literature reviewed, of cases found, of conjectures examined, and of criteria used to select conjectures.

4.1. Phase I: groundwork

Entering iterative triangulation with a well-defined focus improves the potential for developing

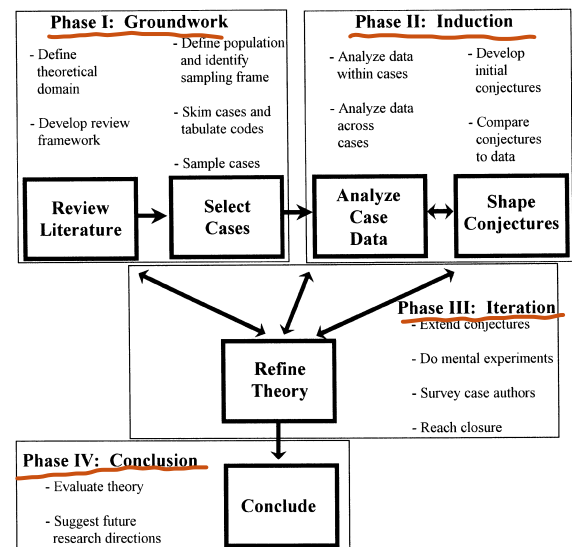


Fig. 1. Methodological process.

quality theory. Phase I consists of groundlaying steps that define methodological and theoretical parameters. Clarifying research questions, constructs of interest, and case search strategies and selection criteria provides a framework that guides later phases.

4.1.1. Review literature

Research preparation begins with an extensive review of diverse, relevant literature. Initially, this review serves to illuminate the dominant constructs, relationships, and theoretical perspectives and the strengths, gaps, and needs of existing literature. This understanding helps specify research questions and constructs of interest which provide the boundaries of the theoretical domain (Bullock and Tubbs, 1987). Constructs should be chosen based on their frequency of inclusion in existing research and defined broadly and abstractly enough to facilitate their potential study (Lucas, 1974). Research questions and constructs, however, should remain flexible, enabling capitalization on new insights and serendipitous findings throughout the process.

Reading works that are beyond traditional OM research broadens theoretical boundaries and strengthens linkages to a wider base of existing literature. Placing works in theoretical categories (e.g., based on commonly held assumptions) may help manage the bulk and diversity of information found in such a broad literature review. This review framework can also prove useful in later phases of the process, suggesting potential sources for increasing case diversity and providing a means of enhancing conjecture heterogeneity.

The illustrative study began with a review of technology literature in sociology, engineering, economics, and organization studies (e.g., organizational theory/behavior and strategic management), as well as in OM. A two-dimensional review framework, comprised of assumptions from Burrell and Morgan (1979) about the nature of society (regulation or radical change) and the assumptions of Pfeffer (1982) about human actions (deterministic, purposive, emergent) provided a basis for distinguishing six theoretical perspectives. This extensive review resulted in an assessment that the literature lacks a clear articulation of the nature of diverse AMT designs and their interrelationships with five constructs of interest (structure, strategic focus, managerial ideology, hu-

man resource management/industrial relations practices (HRM/IR), and operational infrastructure). Consequently, the objectives of this study became further specified as follows: (1) To develop an AMT design construct precise enough to discriminate between flexible, computerized designs, yet general enough to cover the broad class of manufacturing process technologies; (2) To place that construct within a nominological net of AMT design's interrelationships with the five constructs of interest during the design process.

4.1.2. Select cases

Defining a research population assists in the identification of an adequate sampling frame (a pool of potentially useful cases). Population definition requires specifying case search strategies and selection criteria. Employing several search strategies increases the size and diversity of the sampling frame and minimizes search biases (Larsson, 1993). Search strategies can include using reviews and bibliographies from relevant literature, library computer searches, case catalogues, case collections, and experts' referrals. Potential case sources include research journals, research books, unpublished papers, dissertations, government studies, and teaching cases. The broad literature review may suggest sources outside the usual OM publications. Attempting to find cases emanating from as many theoretical perspectives as possible (e.g., from each theoretical category in the review framework) can increase case diversity. However, this may require additional effort, as in the illustrative study certain perspectives were replete with case research, while others were nearly barren.

Specifying selection criteria serves to identify the minimum number of cases needed and to ensure the existence of sufficient information within each case for research purposes. A preliminary, surface search can help determine appropriate criteria. Liberal, rather than overly restrictive, criteria enable accumulation of a larger, more diverse sampling frame. Greater case variety increases choice when theoretically sampling cases during induction and fosters the development of a more creative and generalizable theory.

Selection criteria should include guidelines for case contexts, content, length, and quantity. Case

design should not be a selection criteria as differing styles, such as descriptive, explanatory, exploratory, and teaching cases, often provide unique insights into a phenomena (Larsson, 1993). Basing contextual and content criteria on the theoretical domain retains case focus (Bullock and Tubbs, 1987). The illustrative study limited case context to manufacturing facilities after 1980, to highlight computerized manufacturing technologies. Requiring a minimum of two pages of technology description focused selection on cases containing adequate information to develop the AMT design construct. A two page minimum of organizational context description excluded purely technical cases, such as some engineering cases, to enable examination of AMT design interrelationships with one or more of the constructs of interest.

Limiting case length and quantity are pragmatic criteria necessary to avoid overly taxing research resources while ensuring an adequate supply of cases. In the illustrative study, restricting case length to 60 pages included longer cases, while eliminating full texts. To provide a large enough sampling frame from which to theoretically sample cases, this study sought at least 50 cases fitting the selection criteria. The preliminary search resulted in approximately 20 cases, suggesting that an in-depth search could easily uncover the remainder. The formal search resulted in the location of approximately 100 cases fitting the selection criteria.

Skimming sampling frame cases can improve sampling effectiveness and efficiency. In addition to taking brief notes, coding which key constructs are described and in what depth, and arranging data within a table, provides a useful overview of case contents. See Fig. 2 for an example from the illustrative study. Skimming also aids in developing a skeletal view of potential constructs, relationships, and theory.

Developing a ‘theoretical sample’ (Glaser and Strauss, 1967) of cases involves two steps with differing goals. The goal of the initial sample is optimal inductive potential. Several techniques can improve the usefulness of the initial sample. First, choosing cases based on their representation of all or most of the constructs of interest maximizes theory coverage within cases. Second, selecting cases that highlight polar extremes (Eisenhardt, 1989) facilitates comparisons. Third, choosing cases that are ‘open’ to interpretation (i.e., give lots of detail and description of what took place, not just the researchers’ conclusions) may provide greater insight into the nature and ‘why’s’ of complex interrelationships.

The second sampling step entails adding cases to fill conceptual and theoretical gaps discovered during induction. For example, in the illustrative study, two cases were added that concentrated on the technology design–strategy relationship to clarify the

Case	Research Design			Reported AMT Characteristics			Reported Xs**				
	Style	Level(s) of Analysis	Theoretical Perspective(s)	System	Machinery	Operator Tasks	X ₁	X ₂	X ₃	X ₄	X ₅
CODING SCHEME EXAMPLES Theoretical Perspectives: Case Styles: OM = Operations Mgt (Traditional) D = Descriptive TIM = Technology and Innovation Management T = Teaching Eng = Engineering Ea = Explanatory (deductive) ST = Socio-Technical Theory/Work Humanization Eo = Exploratory (inductive) LP = Labor Process/Marxian Levels of Analysis: I = Individual Reported Constructs - Depth of Description S = Subunit 0 1 2 3 4 5 P = Process <-----> O = Organization None Moderate In-Depth/Detailed											

** Xs = Constructs of Interest (e.g., strategic focus, structure, operations infrastructure)

Fig. 2. Example of sampling frame table.

role of strategic focus within AMT design's nomino-logical net. To avoid being overwhelmed by data, theorists may want to specify an outer case limit at the start. Eisenhardt (1989) suggested four to ten cases as ideal when using original case studies for induction. With less information per existing case and a desire to increase case diversity, 20–30 cases may be more appropriate for iterative triangulation.

Technology cases cover an assortment of AMT designs and their relationships to the constructs of interest with varying degrees of description. Thus, in the illustrative study, it was determined that a limit of an additional 20 cases (for a maximum of 30 sampled cases) was required to balance the need for numerous, diverse cases with the potentially unwieldy accumulation of case data. Appendix A provides an abbreviated list of cases from the illustrative study, exemplifying the diversity of case sources and styles, with theoretically sampled case studies marked. McCutcheon and Meredith (1993) provided an appendix of additional OM-related case studies and an in-depth discussion of case study styles and development methodologies.

4.2. Phase II: Induction

Mintzberg (1979) claimed that developing quality theory requires two steps: (1) well-done detective

work and (2) relevant, creative leaps. These steps correspond with phases II and III of iterative triangulation, respectively. Phase II consists of several techniques to analyze case data, to track down patterns and consistencies, and to shape initial conjectures. Phase III describes iterative means of refining the emerging theory by creatively generalizing beyond the data.

4.2.1. Analyze case data

Case analysis techniques—both within and across cases—can amplify theorists' abilities to detect patterns and to develop an understanding of the 'why's' underlying those patterns. Case analysis begins with a thorough study of each case. Within-case analysis enables the theorist "to become intimately familiar with each case as a stand alone entity" before searching for patterns across cases (p. 540 of Eisenhardt, 1989). Thomas (1994) used a 'holographic' approach, asking "if I were to develop a theory from this case alone, what would it look like?" In the illustrative study, visualizations of the AMT design and its interrelationships were developed from each case. For example, the AMT design construct became focused on interrelated technical (machinery) and human (task) elements of the technology.

From thorough readings, the coding scheme used earlier can be expanded to code characteristics of

Case	Context Characteristics			AMT Characteristics			X Characteristics**				
	Industry/ Product	Extremity of Change	Nature of Change	Factor 1	Factor 2	Factor 3	X ₁	X ₂	X ₃	X ₄	X ₅
CODING SCHEME EXAMPLES											
Extremity of Change 1 2 3 4 5 <-----> Low High (Incremental) (Discontinuous)				AMT Characteristics Factor 1 - Operations System/Process C = Customization CT = Continuous SB = Small Batch Oth = Other LB = Large Batch MP = Mass Production (Traditional Assembly Line)							
Nature of Change 1 2 3 4 5 <-----> Competence Competence Enhancing Destroying				Factor 2 - Machine Automaticity 1 2 3 4 5 <-----> Low High				Factor 3 - Operator Task Complexity 1 2 3 4 5 <-----> Low High			

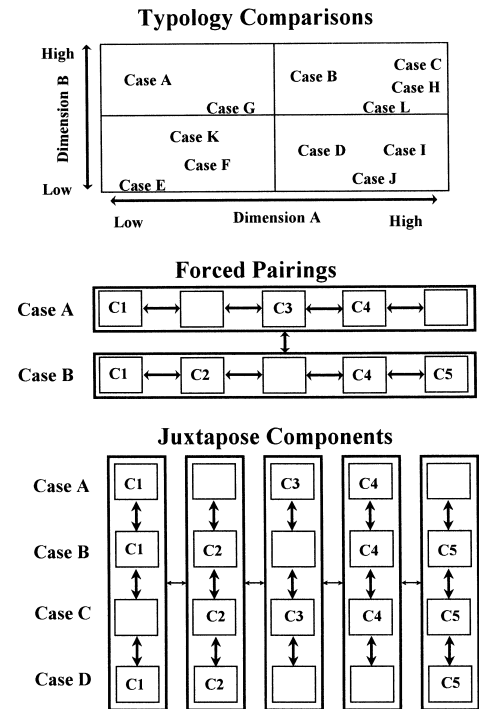
** Xs = Constructs of Interest (e.g., strategic focus, structure, operations infrastructure)

Fig. 3. Example of sample table.

key constructs. Basing codes on existing operationalizations whenever possible can improve theoretical utility by fostering research comparisons and theory testing. Case characteristics such as research design (e.g., author's theoretical perspective) and contextual factors (e.g., case site) may also be coded. Tabulating these codes helps manage case data by identifying in which cases certain characteristics were observed and facilitates cross-case comparisons by identifying particularly similar or different cases. Fig. 3 provides an example from the illustrative study. Codings may be refined and tabular detail increased as the nature of the developing theory becomes more clear. When supported by anecdotal evidence, tables also provide an excellent means of reporting study conclusions (e.g., see Mintzberg et al., 1976).

Three cross-case analysis techniques may aid detection of case patterns. When applied in succession, these techniques increasingly magnify case similarities and differences (see Fig. 4). The first technique, typology comparisons, consists of categorizing cases (Eisenhardt, 1989). In the illustrative study, cases were separated within a typology of AMT designs. AMT designs were placed within one of four quadrants depending upon the degree of machinery program content (Dimension A) and operator task program content (Dimension B) within the design. Program content denoted the degree to which operator or machinery responses to stimuli, variations in production materials or information, were pre-specified. Operator tasks were programmed via task descriptions or procedures, machinery via mechanical designs or computer programs. This typology simplified a search for within-group similarities and inter-group differences.

The second tactic involves forced, random pairings of cases, which may break simplistic frames (Eisenhardt, 1989; Thomas, 1994). As patterns emerge, comparing cases in threes or fours extends patterns. In the illustrative study, forced comparisons uncovered minute, yet significant AMT design differences in similar-design contexts that required further conceptualization. The task program content (TPC) and machinery program content (MPC) dimensions became further specified by developing multiple indicators of each dimension. Specifically, task complexity and operator discretion were identi-



Cs = case components (e.g., construct indicators, key constructs, relationships, etc.)
Blanks = components not sufficiently described in the case for analysis

Fig. 4. Cross-case analysis techniques.

fied as indicators of TPC. As TPC increases, task complexity and discretion are reduced. Greater automaticity, information processing and storage capabilities, and process integration appeared indicative of higher levels of MPC.

Juxtaposing components (first construct indicators, then key constructs, construct relationships and interrelationships) is the third tactic (Thomas, 1994). This technique proved particularly effective for clarifying construct definitions and the nature of construct interrelationships in the illustrative study. The five constructs of interest became conceptualized as continua with the poles signifying a focus on flexibility or control. Control-oriented poles denoted efforts to reduce uncertainty and maintain stability through rational mechanisms. Flexibility-oriented poles signified responsiveness, adaptation, and innovation through informal, decentralized actions. Interrelations typically resulted in an assessment of the organization as predominantly flexibility- or control-oriented.

4.2.2. *Shape conjectures*

Tentative patterns observed in the data analyses provide the basis for developing initial conjectures (hypothesized if–then relationships; Weick, 1989). As with grounded theory building, comparing conjectures across cases acts as a replication logic, clarifying constructs, relationships, and the emerging theoretical framework (Eisenhardt, 1989; McCutcheon and Meredith, 1993; Parkhe, 1993). However, in iterative triangulation, insufficient case evidence does not necessitate discarding a conjecture, as existing cases will rarely describe all components of an emerging theory.

In the illustrative study, the induction phase resulted in a tentative conceptualization of AMT design and its placement within a nominological net of the five constructs of interest. AMT design was conceptualized as the interaction of TPC and MPC within production workstations. While most sampled cases provided adequate information on TPC and MPC indicators, case authors often described AMT designs in terms of the nature of operator work, the overall production system, and/or process control. Tapping the diversity of case authors' perspectives provided a richer view of AMT design, as conjectures became focused on the nature of MPC–TPC interactions. Fig. 5 illustrates the results. The four quadrants or ideal-types (QI–QIV) are labeled with

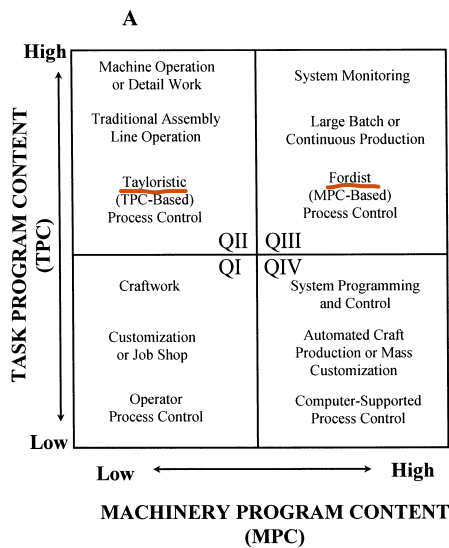


Fig. 5. AMT design typology.

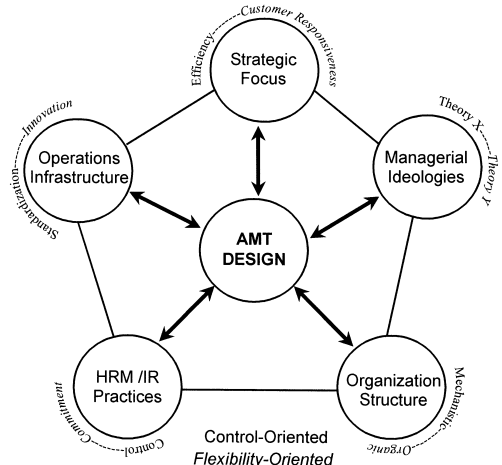


Fig. 6. AMT design nominological net.

the typical nature of operator work, the production process, and process control stemming from the TPC–MPC interactions within each design. The typology is highly simplified for illustration purposes, as actual technologies may cut across multiple quadrants.

The complexity and depth of case descriptions facilitated placement of the AMT design construct within a nominological net with the constructs of interest (see Fig. 6). Each construct is labeled with the poles of its particular flexibility (italics)—control (non-italics) continuum. Initial conjectures focused on assessing whether a predominantly flexibility- or control-orientation resulted in more successful AMT designs. However, each orientation for the overall organization (i.e., the nominological net) and within the specific constructs appeared to have both merit and limitations. Excessive control typically fostered stagnation, rigidity, and mistrust, while extreme flexibility often resulted in wasted resources, redundancy, and chaos.

The longitudinal nature of the sampled cases then enabled conjectures to become focused on the design process. While design processes varied considerably across cases, the nature of interrelationships within the nominological net appeared to both constrain and be altered through the design process (signified by the double-headed arrows in Fig. 6). More specifically, a noticeable pattern emerged: a cycle of design, unintended consequences, reassessment, and

design change. In most cases, this cycle repeated itself at least once if not several times. Results ranged widely from a highly successful AMT design and supportive nomenclological net (i.e., significantly greater process flexibility and productivity, higher quality of worklife, and/or competitive advantage) to outright failure (i.e., complete abandonment of the AMT design change). This pattern and its dramatically diverse outcomes highlighted two deeper issues. First, why is the design of AMT and its nomenclological net so problematic? Second, what enables or hinders an organization's ability to find a workable AMT design and net during the design process? Addressing these issues required moving beyond the case data.

4.3. Phase III: iterations

Phase III consists of systematic techniques that foster creative leaps beyond case evidence, aiding theory refinement. Iterations between case evidence, existing literature, and intuition help extend, select, and link conjectures from disparate case evidence into a coherent theory. Increasing the quantity and variety of conjectures raises the chance of breakthroughs and potentially improves theory quality (Weick, 1989). Initial conjectures will be somewhat heterogeneous as diverse cases may lead to conjectures stemming from differing case authors' perspectives and levels of analysis. Several techniques may further augment these conjectures. In the illustrative study, conjectures were developed from each theoretical perspective within the review framework. This proved to be a particularly effective and manageable technique for increasing conjecture richness (for additional techniques, see pp. 522–523 of Weick, 1989).

4.3.1. Conduct mental experiments

As existing cases contain limited information, extended conjectures and the emerging theory will become increasingly loosely coupled to the case data. Hence, selecting conjectures becomes more a matter of judgment (i.e., determined by the theorist) than of natural selection (i.e., determined by the environment) (Weick, 1989). The theorist conducts mental experiments, iterating between his/her expe-

riences and assumptions, reviewed literature, and case data to evaluate conjectures. Diverse cases and a broad literature review may increase the heterogeneity and quantity of mental experiments, spurring creativity. Developing linkages between the emerging theory and extant research (cases and reviewed literature) may enhance theory utility by explaining past research contradictions and integrating previously fragmented research works. To improve the coherence of selected conjectures requires consistent application of diverse criteria. Weick prescribed asking, is each conjecture “interesting, obvious, connected, believable, beautiful or real in the context of the (research) problem?” (p. 524)

Surveying case authors provides another means to fill in case blanks and evaluate developing theory. Communication to the individual case authors should include an explanation of the authors' role in iterative triangulation and a coding scheme for the authors to code their own cases. Expanding codes to include customized, open-ended questions, may tap an author's firsthand knowledge of the case context for additional information not included or fully described in the case write-up. Larsson (1993), a rare user of author participation in case surveys, claimed that his high response rate from case authors may be expected, due to researchers' desire to see their work furthered. In the illustrative study, conducting an in-depth interview with an author of a particularly influential case study provided additional case detail and an invaluable opportunity to receive feedback on the emerging theory.

4.3.2. Reach closure

Closure, the stopping point of iteration, marks the point of theoretical saturation, when marginal improvement and learning become small and phenomena become repetitive (Eisenhardt, 1989). Achieving closure requires the synthesis and integration of diverse elements (Mintzberg, 1979). The key to achieving closure is coherence. Without closure, the theory development process may result in many conjectures just as fragmented as those already existing in the literature (Weick, 1989). Cases from the initial sample that were not analyzed may be used to critique tentative conclusions and assess whether closure has been reached. When the developed constructs and theory provide a sufficiently accurate and

comprehensive interpretation of a case, the theorist may declare closure.

Iterative triangulation may result in a variety of outcomes, such as the development of constructs, testable propositions, and/or a comprehensive theoretical framework. The illustrative study resulted in an AMT design construct and a theory of the AMT design process. While a full discussion of these results is beyond the scope of this paper, a brief description of the mental experiments and resulting alterations to the constructs and model developed during induction illustrates the significance of the iteration phase.

In trying to address the questions left unresolved from induction, the iteration phase became focused on a central theme of paradox—the “simultaneous presence of contradictory, even mutually exclusive elements” (p. 2 of Cameron and Quinn, 1988). The author has long had a fascination with paradox, originating with an MBA course focused on paradoxes in group behavior, extended through readings and research in systems thinking, learning organizations, and vicious organizational cycles, and sparked, in this study, by the observation across cases of apparently contradictory elements (control and flexibility) existing or needing to exist simultaneously. This discovery inspired a return to the previously reviewed literature, searching for discussions of paradox, and the addition of paradox-specific literature beyond the AMT topic (e.g., Cameron and Quinn, 1988; Westenholz, 1993).

Iterating between this literature, my intuition, and the case evidence, mental experiments examined the paradoxical nature of AMT design. Extending the initial conjectures, the issue became not which pole predominated, but to what degree did control and flexibility aspects coexist within each construct and throughout the nominological net. The net, while remaining in tact, became increasingly complex as the constructs of interest were reconceptualized as two-dimensional. During the AMT design process, organizations struggle to find a mix of flexibility and control that compliments their environmental conditions and internal competencies.

Several mental experiments suggested that organizations that discover a successful mix develop a capacity for paradoxical thinking—grasping the nature of the flexibility-control paradox within and

across constructs. Paradoxical thinking requires re-assessing the assumptions on which the design of each construct in the net has been based. A pattern emerged of case organizations developing this capacity in one or a combination of three ways. First, numerous cycles of trial-and-error were completed. The effectiveness of these cycles appeared enhanced when shockingly unintended consequences triggered more radical experiments, and/or when these cycles occurred in a forum conducive to radical experimentation, such as a lab on the factory floor but physically or symbolically separated from the existing technology design. Second, stakeholders with divergent perspectives of AMT design and its interrelations were involved in the design process at or near the beginning. These stakeholders often included operators, union officials, vendors, and product development engineers, among others. Third, the design process was led by a transformational champion, skilled at paradoxical thinking and at inspiring it in others. In unsuccessful organizations, quite the opposite was true. The project was frequently led by a single-minded champion or group, isolated from opposing perspectives. Most common was a technical expert(s) driven to design and develop the state-of-the art technology, usually in the form of a highly computerized, nearly unmanned system.

4.4. Phase IV: conclusion

Phase IV concludes the theory development process by evaluating the theory and suggesting future research possibilities. This phase serves to assess theoretical contributions and to begin bridging theory development with theory testing. Evaluating the theory appraises its utility to researchers and practitioners. The theorist should assess the limitations of the first three phases and delineate theoretical and methodological boundaries.

One of the strengths of iterative triangulation is its potential to provide direction for future research. Phase II data analyses may illuminate additional constructs and research questions for future avenues of inquiry. The refinement of constructs through induction and iterations may enable subsequent studies to test the theory. The developed coding scheme may serve as a basis for large-scale quantitative surveys. If a sufficient number of cases remain un-

sampled from the sampling frame, a case survey could be a logical next study. A case survey entails coding case data and statistically testing hypotheses and theory (see Larsson, 1993). Finally, this method may guide the development of original case studies designed to deepen understanding of the ‘why’s’ behind interrelationships and processes by suggesting key phenomena to be studied.

In the illustrative study, the developed AMT design construct and model may foster paradoxical thinking in researchers and practitioners. Further improvements upon and employment of the AMT design construct may focus attention on integrating human (task design) and technical (machinery design) considerations when developing computerized manufacturing systems. Viewing the AMT design process as the management of paradox suggests the need to reassess assumptions and foster experimentation to aid development of a complementary, albeit tenuous, balance of flexibility and control within the AMT design nomenclological net.

5. Implications of iterative triangulation for OM

OM is faced with the daunting challenge of developing and testing theory at a pace commensurate with the rapid changes in technology and managerial methods occurring in domains that it addresses. Keeping up with these dramatic changes requires theory building processes that enable comparative analyses of complex organizational settings and foster opportunities to question widely held OM assumptions. Existing case studies offer an opportunity to examine effectively and economically, numerous, diverse operations contexts from differing author perspectives. Iterative triangulation contributes a systematic process and specific techniques for tapping the potential of case study analysis in theory development. The methodological approach provides means to clarify multidimensional concepts and to develop a comprehensive theoretical framework representative of complex, dynamic organizational reality.

As Kuhn noted: “The research scientist is not an innovator, but a solver of puzzles” (quoted in p. 244 of Parkhe, 1993). Iterative triangulation provides a unique puzzle-solving process. To spur creativity and

enhance utility, puzzle pieces emanate from diverse case contexts and theoretical perspectives and become linked through numerous mental experiments. The potential outcome is the development of quality theory that integrates previously fragmented literature and advances the theoretical and conceptual foundations invaluable for future OM research.

Appendix A. Cases from the illustrative study

The listed case studies exemplify the diverse sampling frame developed for the AMT design study. Cases theoretically sampled for induction are marked *, with the site name (national location) and industry or production process specified.

Adler, P.S., Goldoftas, B., Levine, D.I., 1996. Flexibility versus efficiency? A case study of model changeovers in the Toyota Production System. A working paper. * NUMMI (US), automobile assembly.

Argote, L., Goodman, P.S., Schkade, D., 1983. The human side of robotics: how workers react to a robot. *Sloan Manage. Rev.* 24 (3), 31–41.

Balaguer, N.S., Preuninger, J.W., 1993. Allen-Bradley: Electronic Manufacturing Strategy. HBS Case Services, Boston, MA.

Berggren, C., 1992. Alternatives to Lean Production: Work Organization in the Swedish Automobile Industry. ILR Press, Ithaca, NY. * Volvo TC and Udevalla (Sweden), auto assembly.

Berting, J., van de Braak, H., 1889. Technological changes in two Dutch factories: control, flexibility, and learning. In: Francis, A., Grootings, P. (Eds.), *New Technologies and Work: Capitalist and Socialist Perspectives*. Routledge, London, pp. 296–325.

Birchall, D.W., Helsby, D., 1984. Automation in biscuit manufacturing. In: Butera, F., Thurman, J.E. (Eds.), *Automation and Work Design*. Elsevier, New York, pp. 600–612.

Chen, K., Easley, J.G., Liker, J.K., Rothman, J., Thomas, R.J., 1984. Human resource development and new technology in the automobile industry: a case study of Ford Motor company’s Dearborn engine plant. The development and utilization of human resources in the context of technological change and industrial restructuring. Department of Labor, The University of Michigan.

- Clark, J., 1994. Computer-integrated manufacturing, supervisory management, and human intervention in the production process. *Int. J. Prod. Econ.* 34, 304–312.
- Corbett, J.M., 1987. A psychological study of advanced manufacturing technology: the concept of coupling. *Behav. Inf. Technol.* 6 (4), 441–453.
- Eyraud, F., Rychener, F., 1986. A societal analysis of new technologies. In: Grootings, P. (Ed.), *Technology and Work: East–West Comparison*. Croon Helm, London, pp. 209–231.
- Fleck, J., 1994. Learning by trying: the implementation of configuration technology. *Res. Policy* 23, 637–652.
- Gerwin, D., Tarondeau, J.C., 1982. Case studies of computer integrated manufacturing systems: a view of uncertainty and innovation processes. *J. Operat. Manage.* 2 (2), 87–110.
- Ghemawat, P., 1995. Competitive advantage and internal organization: Nucor revisited. *J. Econ. Manage. Strategy* 3 (4), 685–717.
- Graham, M.B.W., 1986. A tale of two FMSs. In: Voss, C.A. (Ed.), *Managing Advanced Manufacturing Technology*. Croon Helm, London, pp. 353–366. * FMS A and FMS B (US), defense contractors.
- Hartmann, G., Nicholas, I., Sorge, A., Warner, M., 1983. Computerized machine tools, manpower consequences, and skill utilization: a study of British and West German manufacturing firms. *Br. J. Ind. Relations* 21, 221–231.
- Hirschhorn, L., Mokray, J., 1992. Automation and competency requirements in manufacturing: a case study. In: Adler, P.S. (Ed.), *Technology and the Future of Work*. Oxford Univ. Press, New York, pp. 15–45. * DEC (US), printed circuit board manufacturer.
- Hwang, S.L., Barfield, W., Chang, T.C., Salvendy, G., 1984. Integration of humans and computers in the operation and control of flexible manufacturing systems. *Int. J. Prod. Res.* 22 (5), 841–856.
- Jones, B., 1982. Destruction or redistribution of engineering skills? The case of numerical control. In: Wood, S. (Ed.), *The Degradation of Work? Skill, Deskilling, and the Labour Process*. Hutchinson, London, pp. 179–203. * 5 Aerospace firms (UK), aerospace equipment manufacturer.
- Jones, B., Scott, R., 1986. ‘Working the system’: a comparison of the management of work roles in American and British flexible manufacturing systems. In: Voss, C.A. (Ed.), *Managing Advanced Manufacturing Technology*. Croon Helm, London, pp. 353–366. * Alpha (US), agriculture equipment manufacturer; Turnco (UK), machine tool manufacturer.
- Kestlelout, R., 1989. Introduction of computerised numerical control and the rationalisation of production: the Belgian case. In: Francis, A., Grootings, P. (Eds.), *New Technologies and Work: Capitalist and Socialist Perspectives*. Routledge, London, pp. 165–186. * VM (Belgium), food processing; TW (Belgium), machine tool manufacturer.
- Kirkwood, R., Smith, S., Tranfield, D., 1989. The implementation cube for advanced manufacturing systems. *Int. J. Operat. Prod. Manage.* 9 (8), 5–19.
- Koval, B., Nochevnick, M., 1986. Automation and industrial workers: the preparation and implementation of an international project. In: Grootings, P. (Ed.), *Technology and Work*. Routledge, London, pp. 185–206.
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- Milkman, R., Pullman, C., 1991. Technological change in an auto assembly plant: the impact on workers’ tasks and skills. *Work Occupations* 18 (2), 123–147. * GM (US), automobile assembly.
- Nonas, K., Johansson, J., Linden, G., 1990. Work in arc-welding stations with high technical complexity. *Int. J. Operat. Prod. Manage.* 10 (2), 37–46.
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- Shaiken, H., Herzenberg, S., 1987. Automation and global production: automobile engine production in Mexico, the United States, and Canada. Center for U.S.–Mexican Studies, University of California, San Diego.
- Staehle, W.H., 1984. Job design and automation in the Federal Republic of Germany. In: Butera, F., Thurman, J.E. (Eds.), *Automation and Work Design*. Elsevier, New York, pp. 208–232. * PCB (Germany), printed circuit board manufacturer.
- Thomas, R.J., 1994. *What Machines Can’t Do*. Univ. of California Press, Berkeley. * AutoParts (US), engine and fuel systems manufacturer.

Tyre, M., 1991. Managing innovation on the factory floor. *Technol. Rev.* (October) 59–65. * Italian Finishing (Italy), finishing and assembly plant.

Upton, D., 1990. John Crane UK Limited: The CAD–CAM Link. HBS Case Services, Boston. * JC Reading and Slough (UK), mechanical seals manufacturer.

Wilkinson, B., 1983. *The Shopfloor Politics of New Technology*. Heinemann, London. * Plating (UK), zinc plating process.

Wilson, F., 1988. Computer numerical control and constraints. In: Knights, D., Wilmott, H. (Eds.), *New Technology and the Labour Process*. Macmillan, London, pp. 66–90.

Woods, D., O'Brien, J.F., Hanes, L.F., 1987. Human factors challenges in process control: the case of nuclear power plants. In: Salvendy, G. (Ed.), *Handbook of Human Factors*. Wiley, New York, pp. 1725–1767.

Zuboff, S., 1988. *In the Age of the Smart Machine*. Basic Books, New York. * Piney Wood (US), paper pulp manufacturing process.

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