Treatment of Variability in OM Topics: Survey and Research Potential

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Abstract: The field of Operations Management continues to evolve and encompasses a broad range of topics, themes, paradigms, and methodologies. The dynamism of Operations Management research is characterized by its relative atheoretic nature and a shifting focus to new topics away from the well-researched ones. Operations Management literature has seen numerous calls for theory-building as well as for bridging the gap between research and practice. In this paper, we posit variability as a fundamental construct that could explain the baffling diversity of the field as well as its progression in time. We present a schema to situate the evolution of different topics and argue that such a schema would be useful in informing on the future directions as well as aid in the theory-building efforts and making methodological choices.

Keywords: Operations management, Variability

Introduction

Operations management (OM) is concerned with 'systemic transformation process to convert a set of inputs into outputs' (Bayraktar et al. 2007). It is difficult to pinpoint when OM came into being, however given its obvious manufacturing connotation, Scientific Taylorism in the early 20th century is commonly understood to be the genesis of OM as a formal discipline (Sprague 2007; Bayraktar et al. 2007). Since its early pre-occupation with machine-level productivity, OM has transformed into a functional field within management (Filippini, 1997) encompassing diverse topics and themes, and has seen paradigmatic changes and methodological diversity. Along the way, OM has struggled to reconcile research with practice, debated right balance between axiomatic and empirical methods, been criticized for weak theoretic foundations, and even faced identity crises. The baffling dynamism of OM has motivated many reviews & discussion papers to posit directions for future research agenda (Buffa 1980; Miller and Graham et al. 1981; Amoako-Gyampah and Meredith 1989; Filippini, 1997; Meredith and Roth 1998; Pannirselvam et al. 1999; Gupta et al. 2006; Skinner 2007; Bayraktar et al. 2007; Craighead and Meredith 2008; Taylor and Taylor 2009; Voss 2010; Gunasekaran and Ngai 2012; O'Brien 2013). All reviews provide excellent commentary on how the field has evolved and what avenues exist for its future growth. But they do not offer explanation on why OM has followed particular evolutionary paths, or why interest on some topics has faded while other topics have come up. Our study is motivated by the question of causality of OM's evolutionary path.

Throughout its existence as a modern discipline, performance has been the mainstay of OM's focus. Even as it has diversified and splintered into multiple topics and themes of research enquiry, it has sought to develop models, frameworks, methods, or understanding of variables and relationships to attain higher levels of efficiencies, quality, or responsiveness while adhering to its central purpose, i.e. transformation processes to convert inputs to outputs. Pursuit of efficiency requires an ability to define and measure the variables involved in the phenomena. We argue that such a pursuit rests on a deterministic approach under which the researcher defines, isolates, and measures the variables contributing to efficiency, and proposes methods to control them. To do this, the researcher must conceptualize the phenomenon as a model, i.e. a defined interplay of some defined variables, isolate the particular domain to which the participating variables belong, and systematize the variables to be measured *ceteris paribus*. In such a process, the researcher must make a set of essential assumptions. Since such assumptions are dictated by the researcher's preferences, methodological choices, or inadequate information, they have the effect of distancing the model from the actual reality. Inherently, every efficiency-seeking model is an abstraction, and therefore must face some form of variability. Seen this way, variability is simply the measure of distance between the model and the actual reality.

We argue that dealing with variability *is* a central concern for OM research and practice, and ask whether variability as a construct could offer explanations for its evolution. This paper is organized as follows. In the next section, we trace the evolution of OM highlighting the key events or influential papers that appear to have shaped its course. Following this, we view OM evolution through the variability lens. In doing so, we examine whether managing variability might have been the subtext in the research efforts and outcomes. Next, we build on our arguments and literature to propose a schema for situating the evolutionary research trends, and illustrate it with examples from two topics. Finally, we discuss the implications of our work before concluding with closing comments.

Evolution of OM research

Early OM was characterized by its focus on labor efficiency and practice-orientation. Frederick W. Taylor's 1911 work – *The Principles of Scientific Management* – was a compilation of management principles to maximize the production efficiency of application of manual labor to machines. Labor efficiency continued to be the main focus as Ford and others adopted scientific management methods. Scientific management was rooted in quantitative methods, empiricism and strong connection with practice (Bayraktar et al. 2007). A review of OM literature reveals three distinct phases in its evolution (Swamidass 1991; Filippini 1997; Sprague 2006):

a) Scientific management phase (1930's and 40's): Grounded in quantitative methods and empiricism, focusing on machine-level productivity, and largely descriptive in nature.

b) Normative/deductive (OR/MS) phase (1950's and 60's): Research in this phase used conceptual or axiomatic models grounded in mathematical techniques with little connection to the actual reality. Models assumed idealized, rational players and only included those aspects of the phenomena that could be mathematically solved. Research outcomes were useful in situations where models rested on fewer assumptions and were thus closer to the actual reality, such as short-term forecasting, inventory control, and optimization techniques for static allocation problems such as transportation routing, cutting stock, facility location etc. Despite their achievements, OR/MS researchers often ended up chasing weak problems that had little relation to actual reality; 'mathematical rigor dominated the concern for practical application' (Hayes 1992; Bertrand and Fransoo 2007). OR/MS phase generally addressed departmental problems, and did not extend to the factory or the enterprise.

c) Functional phase (1970's and 80's): Was characterized by several shifts. First, OM scholars noted the growing irrelevance of OR/MS and called for an urgent need to re-establish focus on practical applications in organizations (Ackoff 1979; Buffa 1980; Miller and Graham et al. 1981; Andrew and Johnson 1982). Second, industry showed that remarkable improvements are possible without recourse to rigorous research. Japanese manufacturing methods such as Toyota Production System (TPS) showed substantially large improvements in labor and capital productivities, defect rates, inventory levels and cycle times, none of which were predicted by the research models (Hayes 1992). Third, with the rise of MRP, OM expanded from its earlier departmental niche to factory or enterprise, and began to be seen as a functional field of management (Swamidass 1991; Filippini 1997). Fourth, as researchers began to pay attention to the industrial practice, several profitable lines of enquiry emerged which went beyond the enterprise. This led to several calls for empirical research and methodological diversification (Meredith et al. 1989; Flynn et al. 1990; Swamidass 1991; Scudder and Hill 1998; Meredith 1998; Coughlan and Coughlan 2002; Stuart et al. 2002; Voss et al. 2002; Slack et al. 2004; Voss 2005; Barratt et al. 2011; McCarthy et al. 2013). This phase has seen significant expansion of OM agenda into new topics such as Supply chain management, Lean manufacturing, Agile manufacturing, Six sigma quality; and into inter-functional issues by interfacing with marketing for New Product Development, with OB/HR for behavioral aspects of operations, and with strategic management for international operations (Karmarkar 1996; Chase and Zhang 1998; Bendoly et al. 2006; Ketchen and Hult 2007; Miles and Snow 2007; Karmarkar and Apte 2007). It must be emphasized that most of the work in this phase has been empirical or heuristic in nature and represents a return from the earlier OR/MS phase to OM's empirical roots.

Current state of OM research

Despite its exuberance and dynamism, OM research has been short on theory-building as noted by several scholars. Theories are critical for the enduring success of the field as they are 'nets cast to catch the world: to rationalize, to explain, and to master it' (Popper 2005; pp 37-38). Meredith (1993) notes the lack of high-quality theory-building effort in OM and argues that empirical research backed by strong conceptual and methodological base is necessary for credible theory-building efforts. Meredith (1998) cites the advantages of case study and field research methods as adjunct to rationalistic research methods to obtain outcomes with greater generalizability. Wacker (1998) discusses how research methods can contribute to building good OM theories. Schmenner and Swink (1998) postulate a set of 'laws' of OM and offer the theory of 'swift, even flow' and the theory of performance frontiers.

We argue that the weak theoretic anchoring of the field makes it vulnerable to fragmentation into multiple research streams. Further, a search for causal factors behind theoretical weaknesses would remain incomplete unless we return to the roots of the field and gain an understanding of its motivational drivers as it evolved over time. In particular, we argue that search for superior and measurable performance in operations has been the dominant motivation of researchers as well as practitioners. The fundamental focus of the field being transformation processes between inputs and outputs, efficiency remains the prominent measure of such superior performance. Thus it would be instructive to examine how efficiency has been treated by OM through its history. We examine this aspect in the next section.

An alternate view of progression of OM research

Despite its fragmentary nature, OM research maintains focus on performance. Its various outcomes such as models, frameworks, methods, or theory-building efforts seek to achieve greater efficiency, quality, flexibility, or other attributes of goodness. We assert that efficiency is a necessary attribute of all else, i.e. superior quality or flexibility would cease to be of interest if it is not accompanied by efficiency. Our argument that efficiency is necessary but not sufficient and other attributes are insufficient without it is defended on common intuition, while noting that Japanese methods owe their success to their ability to disconfirm the trade-offs between efficiency and other attributes, which was the prevalent wisdom at the time (Skinner 2007).

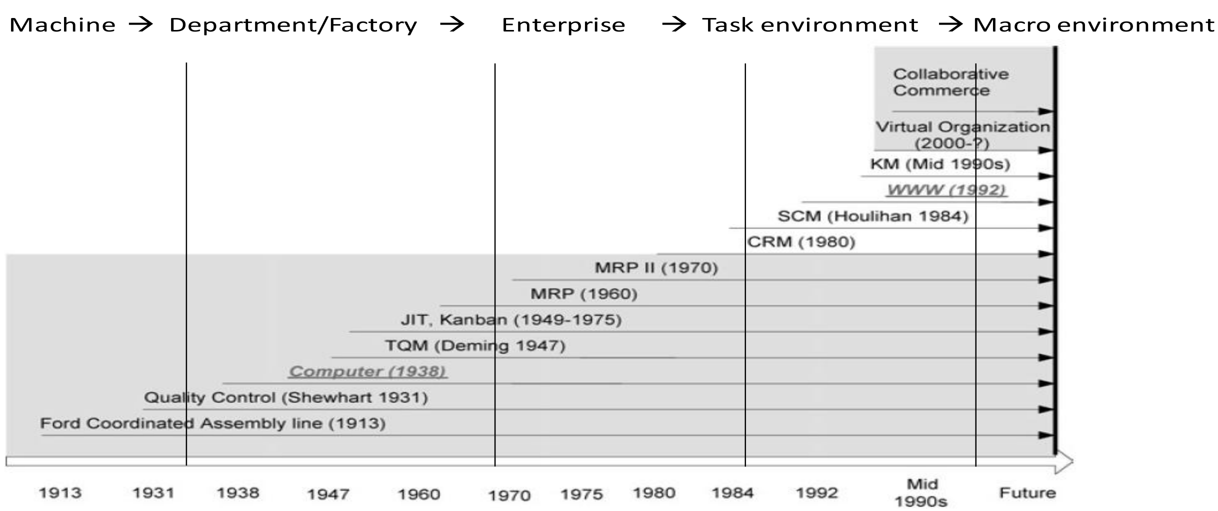
Efficiency is a ratio of two variables, each of which must be amenable to strict definitions and precise measurability. Since efficiency is a property of process performance, it must encompass all required process variables. In reality however, such variables may not be fully identifiable, or may not support strict definitions or measurability. As an example, machine-level productivity involves human manual element and may involve unknown other variables, which cannot be precisely defined or measured. Thus, any variability arising from known and unknown variables ought to have a strong bearing on the efficiency, and ought to be a major consideration in the research design. We note that managing variability is a basic thrust of the theory of 'swift, even flow' proposed by Schmenner and Swink (1998). Accordingly, our discussion appeals to this theory as we review the progression of OM research through the lens of variability.

a) In the first phase anchored to Scientific Management, OM research was empirical and descriptive, and used quantitative methods. Taylor was principally concerned with productivity maximization. However, his prescriptions on piece rates, machine productivity calculations and insistence on the 'best man for the job' leaves no doubt that determinism was the main motivation. In parallel, the time and motion studies by Gilbreth led to standardization of work methods towards obtaining predictably efficient labor productivity. Such standardization led to productivity moving in a narrow range, and thus acted on reducing the variability of human element. These methods were implemented most notably by Henry Ford, with attendant improvement in productivity and predictability. While this has not been explicitly stated in the texts on these historical events, variability reduction was the natural outcome of the maximization effort, even though it may have been adjunct to the main purpose.

b) In the OR/MS phase, optimizing labor & capital productivity continued to motivate the research methods (Sprague, 2007; Bayraktar et al. 2007). Throughout this phase, research studied idealized problems abstracted and stylized from actual reality. Methodological adherence to mathematical modeling indicated the researchers' preference to treat OM as akin to natural sciences. Most of this research concentrated on operations research methods and optimization problems such as scheduling, inventory problems, facility location, facility layout, Spanning trees, network design, cutting stock, vehicle routing, capacity decisions etc. Later research in this phase focused on variants of these themes, e.g. resource constrained scheduling, time constrained scheduling, etc. Some of these problems, e.g. vehicle routing, or facility location proved to be computationally challenging (NP-Hard) and their industrial application had to wait until the computing power and algorithms had improved sufficiently. Even so, computational challenges persisted, and the fact that approximate or heuristic solutions were often 'good enough' (Lenstra and Kan 1981) appears to have reduced the appeal of such methods to practitioners.

While deterministic assumptions motivated the core research agenda, some attempts were made to accommodate variability through stochastic scheduling or fuzzy logic especially in project management (Herroelen and Leus 2005). However, they appear to be of little relevance and mostly ignored by the practice (Filippini 1997; Bertrand and Fransoo 2007).

c) The tipping point against OR/MS methods and towards empirical research came with the success of Japanese methods such as JIT, Jidoka, Kanban, etc. These methods disproved the extant belief about performance trade-offs, and showed that it was possible to simultaneously improve on *all* parameters, often by staggering margins (Hayes 1992). In an HBR article, Spear and Bowen (1999) examine Toyota Production System (TPS) and discuss how TPS's four rules ensure smooth flow of the production process while keeping waste to a minimum. Sugimori et al. (1977) describe TPS as a production system designed to 'adjust to changes due to troubles and demand fluctuations control' while arguing that building up inventory to absorb the fluctuations is a poor solution. Such adjustment involves 'short lead times from entry of materials to the completion of vehicle' (Sugimori et al. 1977; pp 554). While TPS rule specifications differ in scope, domain, and operationalization, they share two properties. First is that they uniformly seek to reduce variability. Second and more important, the variability reduction is applied at the level of whole enterprise and encompasses critical supplier and customer connections. Such an enterprise-wide view of variability recognizes that sources of variability exist outside the machine or departmental boundaries and can have severe adverse effect on machine or departmental performance. While the term 'supply chain' was not coined at the time, it is clear that without a such a focus on enterprise-wide variability, none of the results of TPS could have been predicted or replicated by the OR/MS methods.



Source: Adapted from Bayraktar et al. (2007)

Figure 1: Timeline of progression of OM topics

Concern about managing variability is evident from the writings of many OM scholars as they trace the evolution of the field. For example, Bayraktar et al. (2007) point to the fact that MRP and MRP II systems in 1970's and 80's were push systems with centralized decision-making and considered human workers as static inputs to the production process, whereas JIT and Kanban were pull systems that integrate human element and respond to changes and demand fluctuations, thereby focusing on variability. They also show a timeline map of a subset of OM topics from which it is possible to discern OM progression from machine or departmental focus to phenomena beyond the enterprise. Borrowing from Thompson (2011), we distinguish the domain beyond enterprise into task environment (pp: 27-28) and macro-environment (Figure 1).

Commenting on the development of OM in the US, Meredith and Roth (1998) stress the importance of supply chains adapting quickly to unpredictable shifts in customer demands; and building close interfaces between company's suppliers and customers to obtain greater efficiencies in product development, sourcing, production and distribution. Further, they list nine core areas for research in international technology and operations management of which coordinated production planning, plant rationalization, rationalization of global supply chain, and effective use of information technology for enterprise integration are noteworthy. In a special issue on 50 years of production research, O'Brien (2013) notes that early research viewed inventory as an asset while optimizing the batch sizes and economic order quantities. When Japanese treated inventories as cost rather than asset, their focus shifted to production system as a whole, leading to realignment of production systems and eliminating higher order sources of variability. In the same issue, Buzacott (2013) juxtaposes the current state of the field against his personal work experience in three manufacturing companies 50 years back. He lists the challenges of the day as solving optimization and deterministic problems, and notes that departmentally isolated way of working had led to excessive investments. He discusses how the present-day techniques would obviate many of the then problems, adding that present day problems would mostly come from exogenous sources of variability.

Lean production and agile manufacturing address different forms of variability (O'Brien 2013). They differ in the way they address the issues of product variety and variability in product demand (Ben Naylor et al. 1999). Coping with variability is a 'key aspect of lean approach', while agile manufacturing places greater emphasis on "dealing with customer demand variability, flexible assemble-to-order systems, virtual supply chains and use of IT tools" (Hines et al. 2004). Demand volatility, product variety, variability and production volume differentiate lean and agile approaches (Christopher 2000). Lean production is 'most frequently associated with elimination of waste to ameliorate the variability in supply, processing or the demand' (Shah and Ward 2007). Quality Management is another field that has dealt with the problem of variability. Six sigma originated at Motorola in 1985, and was later adopted by firms such as General Electric, Ford, Citigroup, Du Pont, etc. (Schroeder 2000). While very successful in practice, academic attention to the concept did not begin until 2000 mainly due to its atheoretic origins in practice (Linderman et al. 2003). Six sigma seeks to drives out waste by reducing the variability. Defining specific process goals and managing process variability are the core elements of six sigma. While six sigma and lean approach have different origins, 'reduction of variability at every opportunity' is common to both (Arnheiter and Maleyeff 2005).

Discussion

The foregoing brings out two core ideas of this paper. First, variability strongly motivates the development of OM, and explains its dynamism over time. Second, OM's expanding locus from the bounded domain of machine/department to the enterprise and beyond is explained by an unrelenting search for sources of variability and for methods to mitigate it. Having posited variability as a key explicating construct, we argue that research relevance can be described by how it has addressed the issue of variability. Research relevance is measured in terms of its locus within the enterprise or beyond, and its degree of accommodation of variability through design choices. Figure 2 shows a stylized schema to elaborate these ideas.

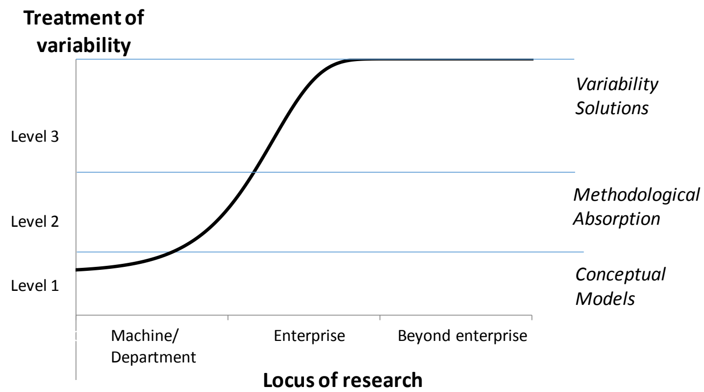


Figure 2: Schema for assessing research relevance

'Locus of research' dimension (X-axis) situates research question on the continuum from machine to enterprise environment. 'Treatment of variability' dimension (Y-axis) categorizes the research design into three levels. Level 1 design systematizes variables and methodologies, and encapsulates them from variability to offer deterministic models. Examples of level 1 include OR/MS optimization problems, aggregate planning, shop scheduling etc. Level 2 designs systematize variables and their relationships, but accommodate variability through appropriate methodological choices. Examples of level 2 include waiting line models, fuzzy/stochastic scheduling, forecasting. Level 3 designs propose solutions to control sources of variability without systematizing variables/relationships or methodologies, e.g. lean methods, JIT, Agile approach etc. A research paper can be represented as a point on the schema, while a focused theme or a topic can be represented as a cluster centroid. The stylized S-curve can be viewed as a relevance boundary. Region to the right of the curve has high relevance, while the region to its left has low or no relevance. The shape of the curve is non-specific and without any support from literature. It derives from the intuition that variability would monotonically increase as the locus boundary expands from machine to department, and to enterprise and beyond. If the state of the research is assessed at different points in time, the suggested schema can deliver insights into how the field has progressed over time. For example, it is possible that a new theme has an empirical origin, and thus begins at level 3 and moves down towards levels 2 or 1 as later research builds theories, models or frameworks. Likewise, research may begin at level 1 with idealized problems and build conceptual models, and later move up to levels 2 or 3 as it moves closer to reality by accommodating variability. Horizontal moves on the scheme capture changes in research locus. We illustrate the schema with two examples.

1. In the first example, we consider resource constrained scheduling and draw three papers without loss of generality. These papers are:

   a. *Resource Constrained Scheduling as Generalized Bin Packing (Garey et al. 1976);*
   b. *A Branch-and-Bound Procedure for the Multiple Resource-Constrained Project Scheduling Problem (Demuelemeester and Herroelen 1992); and*
   c. *Fuzzy Critical Chain Method for Project Scheduling under Resource Constraints and Uncertainty (Long and Ohsato 2008).*

   First paper models a multi-processor job scheduling problem as a resource constrained unordered bin packing problem (bins are resources) to maximize the bin capacity, and provides an algorithm. As the problem is completely systematized, no variability is considered in the research design. Hence, the research is represented by schema coordinates (Level 1, Machine/department). Second paper discusses a branch and bound procedure for resource constrained project scheduling to minimize the project duration, and thus gets the same coordinates. Third paper studies models uncertainty in resource constrained project scheduling by using fuzzy logic and hence has the coordinates (Level 2, Machine/department).

2. In the second example, we consider the theme of JIT and draw two papers:
   a. *Toyota Production System and Kanban System Materialization of Just-In-Time and Respect-For-Human System (Sugimori et al. 1977); and*
   b. *Level Schedules for Mixed-Model Assembly Lines in Just-In-Time Production Systems (Miltenburg 1989).*

   First paper is authored by Toyota engineers and describes how JIT and Kanban systems work to ensure smooth flow with reduced variability (pp 556) and compares TPS performance against those of American and European car makers. Being an empirical paper, it has the coordinates (Level 3, Enterprise) on our schema. Second paper sets up an integer programming model for mixed model assemblies under JIT systems. The locus has moved to machine/department, and the systematized model falls under Level 1 on our schema.

Figure 3 illustrates the two examples suggesting that the relevance of theme in the first example has not improved, whereas the second theme shows greater promise of relevance.

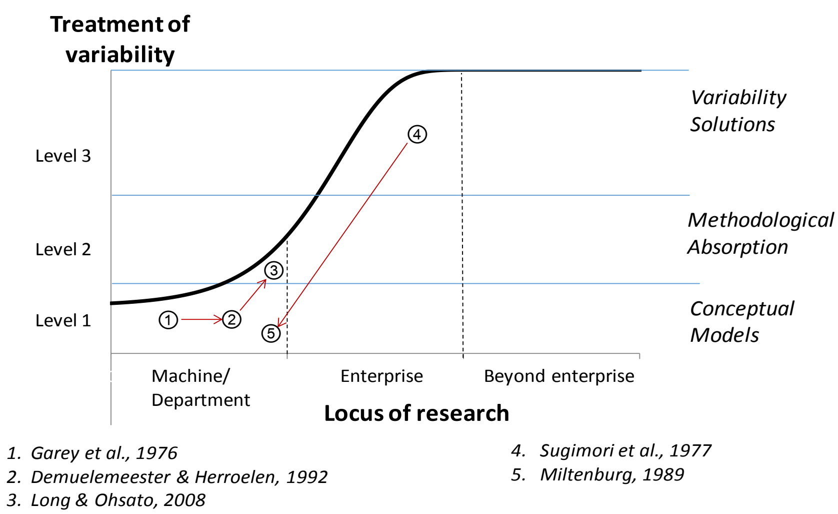


Figure 3: Illustration of assessment of research relevance

Conclusion

In this paper, we survey select OM literature to argue that variability is an important construct that explains the progression of OM research. Based on our findings, we posit a schema to assess the state of research relevance of the field. Such a schema could offer insights into possible future directions for the field. The schema presented in this paper is illustrative, and dimensional units of the axes have only ordinal significance. Further, our arguments derive from a selection of influential OM research papers, and not based on an exhaustive review. Elicitation of characteristics of the levels; and design of metrics for research relevance are left for future work.

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