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**Manufacturing capabilities and performance: a critical analysis and review**

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# Manufacturing capabilities and performance: a critical analysis and review

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**Abstract:** In order to advance scientific knowledge, it is important to maintain consistency regarding the methodologies and units/levels of analysis employed to test a theory's main claims. Thus, this investigation provides a critical examination of the papers that have aimed to test the trade-off model and its competing concepts. The analysis focuses on the methodologies used to examine the validity of such models and theories, and also on the operationalisation of the variables that represent the level of analysis by which those theories are tested. To aid in the investigation, a framework to distinguish measures of performance with an internal and external reference and perspective is proposed. The results show that current methodologies, approaches and rationales used to determine the validity of the trade-off model or its rival concepts observe important limitations, as they do not address the trade-off model's core principles. Those limitations in turn make the results of those studies questionable. Consequently, it is proposed that in order to advance theory in our field, more consistent methods and approaches should be utilised.

**Keywords:** *trade-offs, cumulative capabilities, rigid-flexibility, compatibilities, external reference, internal reference, literature review.*

## 1. Introduction

It has been proposed that the advancement of scientific knowledge is fuelled by the crisis that arises when current theories are found (empirically and/or logically) incapable of explaining phenomena for which they are meant to be explanatory. Theorists and researchers are then faced with the task of proposing better and more encompassing theories that can resolve the new unexplained difficulties (Kuhn, 1963). A fundamental aspect in this process is the uniformity that has to be maintained in terms of the units/levels of analysis of the phenomena that are being studied. Evidently, newer theories have to address the unresolved issues of the old theories using consistent levels/units of analysis. Only if this consistency is achieved, can the tenets and results of the newer theories be considered as legitimate alternatives to those of the old theories.

The field of operations management has also seen attempts by theorists and researchers to replace old theories with more current ones. For example, during the 1980's and 1990's, new theories attempted to understand how firms could achieve high levels of performance across several manufacturing criteria. Some of these efforts (e.g.; cumulative capabilities models) were particularly concerned with explaining the issues that apparently were left unresolved by Wickham Skinner's trade-off model (1969, 1974).

The above being said, it is clear that any new theory that intends to replace or compete with the trade-off model should also aim to explain the relationships between different manufacturing performance measures when observed and measured within an industry-level analysis, not only at the "internal improvement" organizational level of analysis. Consequently, studies that attempt to analyse the trade-off concept and its competing models should utilise measures of manufacturing performance that reveal the status of those criteria and factors of manufacturing when compared at the industry level. Any contending theory to the trade-off model should be at the same level of analysis, with appropriate operationalisations, for its explanation of the same phenomena to be deemed accurate.

Uniformity regarding the methods used to test a theory's claims is another key issue in the advancement of knowledge. Methodologies used to test a theory's claims should be appropriate so that the conclusions derived from the analysis of the data

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3 can not be put into question due to potentially faulty and inadequate methods (Gauch  
4 Jr. 2003).  
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8 Thus, we argue that any theory or concept that attempts to explain or  
9 evaluate the relationship between different manufacturing performance criteria,  
10 strategies or factors without using the appropriate level of analysis can not and  
11 should not be considered as a rival theory or paradigm to Skinner's trade-off model.  
12 Likewise, studies that do not incorporate manufacturing performance measures that  
13 reflect the status of an organisation compared to its competitors (e.g.; industry,  
14 marketplace) clearly fail to adequately address the core themes of the trade-off  
15 concept. We also argue that better and more consistent methods should be used  
16 when theory-testing, particularly when the propositions of the trade-off concept are  
17 put to the test. We also comment on a new and more generalised definition of the  
18 term "cumulative capabilities models", and propose the use of a more consistent and  
19 uniform terminology in our field.  
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29 Specifically, we analyse manufacturing strategy studies that have sought to  
30 evaluate the trade-off model and its related concepts. To aid in this evaluation, we  
31 introduce a framework in which the difference between performance assessments  
32 with reference to industry or competitors and changes in internal performance over  
33 time is established. Using this framework, a literature review reveals that several  
34 studies examining the trade-off model and/or its competing theories have focused on  
35 phenomena that are evidently inconsistent with the original aim of Skinner's model,  
36 which seeks to describe relationships between manufacturing performance measures  
37 when observed at an industry-level of analysis. Furthermore, the methodologies and  
38 variables by which previous authors have investigated the different concepts are also  
39 examined, particularly with respect to the trade-off model. We arrive at the conclusion  
40 that some of these methodologies and variables are difficult to reconcile with the  
41 underlying principles proposed by the trade-off concept. We also offer potential  
42 solutions and recommendations in order to address some of the limitations found in  
43 the reviewed studies.  
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55 The rest of the paper is organised as follows: section 2 offers a brief  
56 exposition and discussion concerning the three theoretical concepts that propose  
57 approaches manufacturing organizations can utilize to achieve a competitive  
58 advantage at the marketplace-industrial level of analysis. Section 3 establishes and  
59 describes a framework to distinguish the difference between performance  
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measurements with reference to competitors or industry, and with reference to changes in internal performance over time. Section 4 offers a summary and discussion of literature that claims to have tested the trade-off model and/or its competing concepts. Finally, section 5 provides some conclusions and recommendations for future research.

## 2. **Theories on the development of high levels of manufacturing performance**

This section introduces several theories and models that have been advanced in the field of operations management. These models focus on the achievement of high levels of manufacturing performance and gaining competitive advantage. We based the selection of these specific theories because (1) they have been proposed by their authors as contending and more complete theories than previous ideas and models, and (2) they have been tested at least once and with results published in highly regarded peer-reviewed journals.

For the sake of clarity in our discussion, several concepts and definitions need to be established. Therefore, a trade-off situation is defined as one in which a firm achieves high levels of performance in one manufacturing capability at the expense of lower levels of performance in one or more capabilities. This definition is consistent with the trade-off model's original tenets: "... no technologically-based system can perform equally well on every performance criterion ...." (Skinner, 1996, p. 8). In this context, a "high" level of performance is defined as an "... outstanding enough .... to create competitive advantage" (Skinner, 1996, p. 6) level of achievement in one or more capabilities. The preceding definitions mean that at the very least, two or more capabilities that are traded-off will not attain a high level of performance at the same time and under the same circumstances.

A compatibility situation means that there is evidence of an overall and similar degree of performance achievement up to a determined level between two or more capabilities. This definition of "compatibility" covers the definition of "cumulative capabilities" that has been used by previous authors. Nonetheless, contrary to the definition of "cumulative capabilities", "compatibility" does not necessarily imply, for example, that just because two or more capabilities observe a generally compatible situation (e.g.; a positive and significant correlation/regression coefficient), such a scenario indicates the presence of at least one observation in which these

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3 capabilities all have achieved or will eventually achieve an “outstanding enough to  
4 create competitive advantage” level of performance.  
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10 We now present the three competing ideas and models. We then provide a  
11 discussion and observations derived from our literature review.  
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15 Trade-offs model: this model was initially proposed by Skinner (1969, 1974),  
16 but also echoed by some other prominent authors in the business and manufacturing  
17 operations literature (e.g.; Porter, 1980, 1985; Hayes and Wheelwright, 1984; Hill,  
18 1995). Its main proposition is that no manufacturing system or unit can perform  
19 equally well and outstandingly enough to create competitive advantage across *all*  
20 manufacturing criteria such as quality, flexibility, speed and time. In order to achieve  
21 a significant competitive edge firms must recognise the existence of these trade-offs  
22 and limitations. Organisations should thus align their structural and infrastructural  
23 resources accordingly to best fit the performance niche identified by the  
24 organisation’s business and operational strategies. A key concept is that this  
25 model’s ultimate focus is on the study of manufacturing performance at the  
26 marketplace, industry level of analysis, and not only on internal improvements over  
27 time. The trade-offs model’s main proposition is summed up by Hayes and  
28 Wheelwright (1984; p. 41): “... price, quality, dependability and flexibility. It is difficult  
29 (if not impossible), and potentially dangerous, for a firm to try to compete by offering  
30 superior performance along all of these dimensions simultaneously, since it will  
31 probably end up second best on each dimension to some other company that  
32 devotes more of its own resources to developing that competitive advantage”.  
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46 Cumulative capabilities models: advanced by several authors and studies  
47 (e.g.; Nakane, 1986; Ferdows and de Meyer, 1990; Noble, 1995; Wacker, 1996) this  
48 concept’s underlying proposition is that by following a predetermined and sequential  
49 path in the improvement of internal performance, some (or all) trade-offs can be  
50 overcome. Different authors support different optimal sequences (e.g.; Ferdows and  
51 de Meyer, 1990; Noble, 1995). A well-known version of these models is the “sand  
52 cone” model, where the typical sequence recommended is focusing on quality,  
53 dependability, speed, and cost efficiency, respectively, as per Ferdows and de Meyer  
54 (1990). Most of the proponents of these models believed this approach as a  
55 competing theoretical alternative to the trade-offs concept. Therefore, the assumption  
56 of this model is to improve not only internal performance over time, but also to  
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3 ultimately attain “outstanding enough” performance levels that would provide  
4 companies with a strategic competitive advantage. This assumption for the  
5 cumulative models makes it a different and rival theory to the trade-off concept. Even  
6 though not explicitly stated, Ferdows and de Meyer (1990, p. 171) implicitly  
7 acknowledge this assumption when they stated that “Since ... our sample is biased  
8 towards large, well performing manufacturing units, we have assumed that most of  
9 them were not operating with slacks in their production systems in 1985”. Other  
10 authors and studies have also viewed the trade-off and cumulative capabilities  
11 models as contending concepts (e.g.; Corbett and Wassenhove, 1993; Collins et al,  
12 1998; Fynes et al, 2000).

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21 It has to be mentioned that a more generalised definition of the term  
22 “cumulative capabilities” has been proposed by some researchers. For example,  
23 Flynn and Flynn (2004) write: “the term cumulative capabilities ...is used here more  
24 generically to describe a situation where a plant has a high level of performance in  
25 more than one capability” (p. 440). However, there are some difficulties<sup>1</sup>with this new  
26 definition. We think that a more consistent and uniform terminology can only aid in  
27 the development and advancement of our field. Therefore, we suggest that the term  
28 “cumulative capabilities models” or “cumulative models” should continue to be  
29 exclusively used to describe those models that affirm that sequential and cumulative  
30 internal improvements can help a firm to overcome some of the manufacturing trade-  
31 offs. Nevertheless, to refer to a situation where firms are capable of achieving higher  
32 levels of performance on more than one capability, we propose that the term  
33 “compatibility” that was defined in the introduction of this section be used.  
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46 <sup>1</sup> *It adds an unnecessary generalisation to a very specific issue that is far from being resolved*  
47 *(i.e.; sequential and cumulative internal improvements lead to higher performance on several*  
48 *manufacturing performance metrics) and clearly in need of more specific and consistent*  
49 *studies and evidence.*

50 *It dilutes the intended purpose of the original proponents of those models (e.g.; Nakane,*  
51 *1986; Ferdows and de Meyer, 1990). Not only did those authors propose that companies*  
52 *could achieve high performance levels on several measures. They also specifically argued*  
53 *that sequential and cumulative internal improvements on each of the manufacturing*  
54 *performance areas could lead to the achievement of high levels of performance across the*  
55 *board.*

56 *At least two on-line dictionaries (Merriam-Webster and Cambridge Advanced Learner's)*  
57 *use words and phrases such as “increasing by successive additions” and “increasing by one*  
58 *addition after another” to define the meaning of “cumulative” respectively. In those same*  
59 *sources, “sequence” is defined as “order of succession” and “a series of related things or*  
60 *events, or the order in which they follow each other” respectively. We see a strong similitude*  
*and complementarities between the meanings of “cumulative” and “sequence”.*



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Rigid-flexibility model: this model was first proposed by Collins and Schmenner (1993). Similar to the cumulative capabilities models, this model also establishes that trade-offs can be avoided. Contrary to the cumulative capabilities models, however, the proponents of this idea argue that it is not necessary for organizations to follow a certain sequence in the development of capabilities in order to achieve “rigid-flexibility”. All an organization has to do is concentrate on building “discipline” and “simplicity” in processes and procedures. Since this concept is also offered as an alternative to the trade-offs and cumulative capabilities models, it is appropriate to assume that the main focus of this model is also to study the relationships between manufacturing capabilities at the industry, marketplace levels, and not only as means of achieving internal improvements over time. Interestingly, only two studies that we found (Collins et al, 1998; da Silveira, 2006) have made an attempt at introducing empirical evidence for testing this model.

The three models described above offer varying and competing views on how a manufacturing organisation can achieve performance levels that can provide it with a competitive edge in industry. Nevertheless, both the cumulative capabilities and the rigid-flexibility models do overlap on a “compatibility” perspective. These two models put forth the argument that high levels of performance can eventually be attained on a number of manufacturing performance measures simultaneously. In order to achieve this outcome, both models propose similar approaches: strong focus on quality-related programs, supplier involvement, just-in-time (JIT) production, workforce commitment and involvement amongst others (see for example the practices included in Ferdows and de Meyer, 1990; and Collins et al, 1998). The key difference is that the cumulative capabilities models prescribe a sequential precedence, a predetermined order in the sequence of the development of manufacturing capabilities, whereas the rigid-flexibility model does not. The proponents of the trade-off model’s rival theories tend to argue that some (or all) trade-offs may be avoided if companies successfully implement modern and more advanced technologies, and consequently they argue that their models are alternatives to the trade-off model. Such statements seem to be based on Skinner’s (1969, 1974) original words in that a manufacturing plant can usually do a superior job on only one or two market demands at any given point in time, the “focused-factory” concept. In fact, Ferdows and de Meyer (1990) and Noble (1995) state as much when they write that: “either the companies which improved performance on more than one measure are paying for that elsewhere (and we are not capturing where in our analysis), or the trade-off theory itself has to be modified” (Ferdows and

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3 de Meyer, 1990; p. 172). “Managers can no longer be comfortable by “competing” on  
4 the basis of one or two capabilities, as would be suggested by the prevalent focus  
5 (trade-off) model” (Noble, 1995; p. 715).  
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10 We acknowledge that there is some evidence showing that by successfully  
11 implementing advanced technologies (e.g.; TQM, JIT, lean manufacturing) a firm is  
12 capable of achieving high levels of performance on two or more manufacturing  
13 capabilities. Nevertheless, such results do not contradict Skinner’s core argument:  
14 No manufacturing system can achieve high levels of performance across *all*  
15 manufacturing capabilities, since any system is delimited by its technologies of  
16 equipment, processes, materials and management (Skinner, 1996). To ever assume  
17 that a manufacturing system can operate without trade-offs is absurd (Skinner,  
18 1992). New technologies might resolve some trade-offs and/or improve some other  
19 ones, but limitations are likely to continue to exist hence the need for strategic trade-  
20 offs (New, 1992; Skinner, 1996).  
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29 Amongst other themes, this section has established that in order for the previous  
30 three concepts to be comparable and viewed as contending theories, they have to  
31 aim to resolve and explain the potential trade-offs that might exist at the industry  
32 levels of analysis and not only on internal improvements achieved over time. This  
33 point will be further discussed in the next section.  
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### 39 **3. A framework for the measurement of external and** 40 **internal performance** 41 42

43 In this section, we advance an explanatory framework for the measurement of  
44 manufacturing performance in relation to industrial competitors and over time based  
45 in part on the concept of performance frontiers (e.g.; Hayes and Pisano, 1996; Clark,  
46 1996; Schmenner and Swink, 1998). The proposed framework will help in our review  
47 and critique of the literature in section 4.  
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53 Schmenner and Swink (1998) define the concepts of performance frontiers as  
54 “The maximum performance that can be achieved by a manufacturing unit given a  
55 set of operating choices” (p. 108). Two types of frontiers are identified: Operating and  
56 Asset. It is also explained that “cumulative capabilities” deal with improvements  
57 within a plant over time, whereas “trade-offs” are reflected in comparisons across  
58 plants at a given point in time. The relationship between these two phenomena (i.e.;  
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3 “trade-offs” and “cumulative capabilities”) and the asset and operating frontiers are  
4 depicted and explained in figure 1:  
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8 **Take in FIGURE 1**  
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12 While the illustration and statements by Schmenner and Swink (1998) are  
13 valuable and insightful, they also have some limitations. For example, they do not  
14 state that any manufacturing firm can, at any point in time, make fair assessments of  
15 both its performance compared to industry and competitors, while also comparing its  
16 own internal performance over a period of time. It is also not made clear that  
17 organisations are able to make these two types of assessments for each individual  
18 area of manufacturing performance (e.g.; quality, delivery, flexibility, costs).  
19 Furthermore, they do not clarify whether the performance frontiers and/or the  
20 phenomena that take place inside their boundaries should be measured, and if so,  
21 how they should be measured.  
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31 Thus, we believe these domain issues need to be explored:  
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- 35 1. Since an organisation can make performance comparisons internally (i.e.;  
36 changes in performance over time) and externally (against industry and  
37 competition levels), these two types of performance assessments should be  
38 clearly distinguished from each other.  
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  - 40 2. There should be a method by which these two levels of performance  
41 assessments should be measured.  
42
  - 43 3. These two levels of performance assessments should be made for each  
44 strategic performance criteria dimension (e.g.; quality, costs, flexibility).  
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49 We now outline potential solutions to the three major points identified above. At  
50 any point in time a company can make assessments regarding its changes in internal  
51 performance over time and its performance compared to industry or competitors for  
52 each manufacturing performance criterion. Figures 2 A & B illustrate this point:  
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58 **TAKE IN FIGURE 2 A & B**  
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Examining figure 2 A & B, we see that at “t2” an organisation can assess its performance both internally (changes of internal performance over time) and externally (status of the firm in relation to competitors). This organisation can make an observation that they have improved their performance “considerably” over the “t2-t1” period of time, and they can also have a fair idea of how, at “t2”, their performance compares to its industrial competitors (e.g.; worst, average or leaders in their industry; worse, equal or better than competitors). Likewise, at “t1”, the firm could have assessed its performance against its industrial competitors and internally over a “t1 – t0” period of time. While these two types of performance references can potentially be related, they are also clearly different. One measures performance against competitors - industry, and the other based on internal improvements or decrements in performance. We define the two types of performance assessments as “external reference” when focusing on industry or competitors comparisons, and “internal reference” for internal comparisons.

We can think of several examples to explain the difference between performance measures of external and internal reference. Here we just propose one practical example: let us present an organization that is struggling with quality difficulties, invests in TQM programs, and after two years, improves its internal quality performance and reduces its rejects from 30 percent to 10 percent. A reduction of 20 percent in rejects in two years could be deemed as a good or even great achievement. Nevertheless, this new level of performance (90% good product) could very well be just average or even unsatisfactory compared to the top performers in comparable industries or against direct competitors, or even across other plants in the corporation. This can be particularly true when a company is very inefficient and contains significant slack resources. It is evident that depending on the type of question that is asked and answered, a researcher can obtain two very different and conflicting pictures regarding the state of the organisation. In other words, and based on the above example, if an analyst exclusively investigated the changes in internal performance over time for an organization, he/she could conclude and report that the company is doing well. However, the reality is that although a 20% of improvement has been achieved, 90% overall good product could be just average or even poor when compared to the top performers in the industry.

While figures 2 “A” and “B” suggest that external and internal performance references can only be assessed perceptually, it could be possible that objective measures of performance can also be used, as long as the sample of subjects is

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3 homogeneous. For example, an objective metric such as “98%” on-time delivery rate  
4 can be used as an “external reference” type of performance, as long as the sample  
5 includes companies from the same industry or comparable competitors, and also  
6 operate in the same country or context (see for example the metrics and sample  
7 used by Dostaler, 2000, 2001). The same criteria would apply if an objective  
8 measure of internal performance such as “30% of improvements in on-time delivery  
9 rate over the past 3 years” was reported. Also, figure 2A only denotes a situation in  
10 which a company actually improves on its previous internal performance levels. We  
11 acknowledge that this may not always be the case. Nevertheless, we believe that a  
12 similar framework of performance reference would apply even if a company observed  
13 a worsening instead of an improvement in performance over time.  
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23 Some of the ideas and concepts proposed above (e.g.; how to measure  
24 internal performance over time) have been utilised and discussed by previous  
25 researchers. This discussion occurs either separately and/or inadequately,  
26 particularly in the study of the trade-off model and related theories. These issues will  
27 be discussed in sections 4 and 5. To the best of our knowledge, this is the first  
28 attempt at including these concepts into a single framework in order to clearly identify  
29 the potential relationships and differences between performance measures of internal  
30 and external reference. This set of relationships and appropriate operationalization of  
31 measures is of critical importance when assessing the theoretical validity of the  
32 trade-off concept and its rival models. This framework will be of help in the analysis  
33 and examination of the adequacy of investigations that have sought to evaluate such  
34 models.  
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#### 45 **4. A critical review of studies that have tested the trade-off** 46 **model and competing concepts** 47 48 49

50 In the critical review summarized in table 1, we identify the type of  
51 performance measures that past studies have used as independent variables (e.g.;  
52 variables that may cause/prevent trade-offs), the dependent variables (variables such  
53 as manufacturing performance measures in a trade-off situation or a compatibility  
54 situation), and the types of performance references (internal or external references)  
55 used to assess the manufacturing performance metrics used as independent and  
56 dependent variables. Additionally, the research methodologies utilised in the  
57 reviewed papers (e.g.; statistical analyses, case studies) are highlighted. This  
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3 categorization and summary will help identify whether the methodologies and  
4 variables used in past research are consistent with the underlying context and  
5 propositions of the theories and concepts that are tested. We only include those  
6 studies and publications that actually claim to provide results in favour and/or against  
7 the trade-off model and its competing theories.  
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### TAKE IN TABLE 1

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21 The analysis of the studies included in table 1 reveals interesting perspectives  
22 and approaches that have been utilised in previous research. Our discussion  
23 concentrates on two main themes: 1) the methodologies utilised to conclude the  
24 existence of trade-offs and/or compatibilities and their explanatory variables, and 2)  
25 the level of analysis chosen (external and/or internal reference metrics) to  
26 operationalise the dependent manufacturing capabilities included in the studies.  
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33 It is evident that the vast majority of studies in table 1 utilise a quantitative  
34 approach to the examination of trade-offs and compatibilities. Of all the papers that  
35 were reviewed, only three of them employed a case study approach (Dostaler, 2000,  
36 2001; da Silveira and Slack, 2001). When using quantitative approaches,  
37 researchers generally gather information from a sample of firms in terms of their  
38 manufacturing performance metrics (e.g.; quality, delivery), the practices they employ  
39 (e.g.; TQM, JIT, TPM), and some other variables that might explain variations in  
40 manufacturing performance (e.g.; production technology, firm size). Several  
41 methodologies are then employed to analyse the data (e.g.; regression/correlation  
42 analysis and related statistical techniques).  
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51 Previous authors have understood the trade-off model and its competing  
52 theories as being mutually exclusive. The prevalent rationale is that when there is  
53 evidence of an overall level of compatibility amongst variables that represent  
54 manufacturing capabilities (e.g.; positive and significant correlation coefficients),  
55 “cumulative capabilities” exist and trade-offs are absent. As Flynn and Flynn (2004)  
56 write, “a positive significant coefficient indicates a cumulative capability, while a  
57 negative significant coefficient indicates a trade-off” (p. 446). Practices such as JIT,  
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3 TQM and similar concepts are utilised to explain significant levels of compatibilities in  
4 a sample of firms (e.g.; Morita and Flynn, 1997; Collins et al, 1998). Interestingly,  
5 contextual variables that may or may not be exogenously fixed or under the control of  
6 firms (Banker and Natarajan, 2001) were also found to be significant determinants of  
7 trade-off and/or compatibility situations between manufacturing performance  
8 measures (e.g.; Corbett and Claridge, 2002).  
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15 As previously mentioned, it is important to maintain consistency when  
16 studying a theory's main claims. Consequently, it should be expected that when  
17 studies have tested the trade-off model's rival theories (and by default, the trade-off  
18 model), methodologies consistent with the trade-off concept's main tenets should  
19 have been employed. Nevertheless, while overall methodologies such as  
20 regression/correlation analysis are helpful to identify general trends and behaviours  
21 amongst multiple variables, they are limited when it comes to testing the trade-off  
22 model's core principles. Put differently, those methodologies are not capable of  
23 clearly and unmistakably identifying whether a firm or firms have actually achieved  
24 high levels of performance on all manufacturing criteria. The existence of positive  
25 and significant relationships between two or more capabilities is not enough evidence  
26 that a firm or firms have achieved, or will eventually achieve, the levels of  
27 performance necessary to attain a competitive advantage at the marketplace level.  
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38 Our observations are reinforced when the asset frontier concept (shown in  
39 figure 1) proposed by Schmenner and Swink (1998) is considered. Compatibilities  
40 between different capabilities can be achieved at the lower levels of performance.  
41 However, it is also hypothesised that such compatibilities will be disrupted by the  
42 effects of the asset frontier. These effects are more pronounced at the higher end of  
43 the spectrum, when the asset frontier starts to dominate the relationships between  
44 capabilities. This means that ultimately, and in spite of the compatibilities observed at  
45 the lower levels in the spectrum, different capabilities will achieve different levels of  
46 performance, a phenomenon which is consistent with the trade-off definition as  
47 proposed by Skinner (1996). The fact that trade-off relationships are dynamic and  
48 can also include stages in which compatibilities are observed has also been  
49 acknowledged by Skinner (1992).  
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59 Therefore, the preceding paragraphs lead us to conclude that overall and  
60 general approaches such as regression/correlation analysis and related



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3 methodologies are limited when it comes to putting to test the foundational principles  
4 of the trade-off model.  
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9 When analysing the adequacy of the operationalisation of the manufacturing  
10 capabilities utilised as dependent variables, it is important to remember that the  
11 trade-off model mainly and principally deals with the compromises that exist amongst  
12 capabilities when compared to industrial-marketplace competitors. Put differently, the  
13 level of analysis suggested by the trade-off model is clearly concerned with  
14 performance assessments with an external reference perspective. The differences  
15 between measures of external and internal references were discussed in section 3.  
16 Hence, it follows that in order to correctly assess the validity of the trade-off model  
17 and its contending theories, studies that examine these concepts should use metrics  
18 of manufacturing performance that determine the status of a firm with respect to its  
19 competitors (i.e.; external reference types of measures) as the dependent variables.  
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28 It is worth noting that two of the most influential studies that claim to have  
29 offered evidence against the trade-off model (Ferdows and de Meyer, 1990; Noble,  
30 1995) have used performance metrics that are inconsistent with the trade-off  
31 concept. Those two studies have utilised performance measures of internal reference  
32 and a combination of external and internal references as the dependent variables,  
33 respectively, in order to derive conclusions about the trade-off and cumulative  
34 capabilities models in their samples. Clearly, manufacturing performance measures  
35 based exclusively on external reference assessments should have been used  
36 instead. We observe that more recent studies (Grobler and Grubner, 2006; da  
37 Silveira, 2006) which also affirm to have provided supporting evidence for the  
38 cumulative capabilities and the rigid-flexibility models, respectively, have also used  
39 performance measures of internal reference for each of the dependent variables in  
40 their studies.  
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50 In fairness to Ferdows and de Meyer (1990), they seem to recognise the  
51 potential limitation of their approach when they wrote "Since ... our sample is biased  
52 towards large, well performing manufacturing units, we have assumed that most of  
53 them were not operating with slacks in their production systems in 1985". Grobler  
54 and Grubner (2006) also seem to make a similar assumption when they wrote: " ....  
55 there may be an overall bias towards high-achieving plants" (p. 467). Nevertheless,  
56 such assumptions are difficult to justify because the absence of measures of external  
57 performance that can be used as the dependent variable makes it difficult (if not  
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3 impossible) to examine the core of the theory they are trying to test, which in turn  
4 violates one of the requirements for the growth of knowledge (Popper, 2002a).  
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8 On the other hand, several studies (e.g.; Schroeder et al, 1996; Mapes et al,  
9 2000) have used manufacturing performance measures based on external reference  
10 assessments. We think this approach is more consistent with Skinner's concepts,  
11 and the appropriate level of analysis that should be used when assessing dependent  
12 manufacturing performance variables in studies that examine the trade-off model and  
13 its competing theories and ideas.  
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19 In addition, it is also observed that, while the sand cone model (Ferdows and  
20 de Meyer, 1990) and similar concepts have been widely cited and discussed in the  
21 operations management literature, no single study that tests whether sequential and  
22 predetermined internal improvements (internal reference) actually lead to the  
23 achievement of high levels of performance (external reference) was found. This is  
24 surprising, considering the attention and relevance that such models and concepts  
25 have garnered over the past two decades.  
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33 Our discussion in this section highlight important limitations in current  
34 approaches used to study the validity of the trade-off model and its rival concepts. In  
35 particular, inadequacies in methodologies used to determine whether firms actually  
36 achieve high performance along manufacturing criteria and operationalisations of  
37 performance metrics have been identified. Nonetheless, there is also some evidence  
38 of studies that offer a more consistent approach to analyse the trade-off model. for  
39 example, Fillipini et al (1998) and Corbett and Claridge (2002) include an analysis of  
40 whether organisations actually achieve superior performance across the various  
41 capabilities in their studies. The firms included in those two papers are grouped and  
42 ranked into various levels of achievement, and subsequently they are categorised  
43 according to the number of capabilities in which they have attained superior  
44 performance. Interestingly, the analyses in both studies reveal results that are more  
45 consistent with the overall predictions of the trade-off and focused factory concepts:  
46 the number of firms that achieve high performance drastically diminishes as the  
47 number of capabilities included in the analysis augment. In other words, attaining  
48 superior performance across multiple criteria is difficult.  
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We propose that future studies that focus on the trade-off model and/or its  
related theories, in addition to using general and overall methodologies such as

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3 regression/correlation analyses, also utilise approaches capable of clearly identifying  
4 whether firms actually achieve an outstanding enough to create competitive  
5 advantage performance across all or multiple manufacturing criteria. It is also  
6 recommended that such criteria should be measured with an external performance  
7 perspective, and not with an internal reference. These recommendations are more in  
8 line with the principles outlined by the trade-off model. Examples of these  
9 recommendations are shown in the papers by Fillipini et al (1998) and Corbett and  
10 Claridge (2002)  
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18 Our conclusion is that the lack of appropriate operationalisation of scales and  
19 variables, and the use of inadequate methodologies and approaches are important  
20 and current issues in research that examine the trade-off model and its competing  
21 theories. This clearly limits the advancement and development of operations strategy  
22 theory. The results and conclusions derived from these studies are questionable in  
23 terms of the validity of the claims that the trade-off model's foundational ideas and  
24 concepts have been refuted. Also, while there is some evidence that firms can  
25 achieve high levels of performance on more than two capabilities, a detailed  
26 examination of the relevant literature leads us to conclude that no investigation has  
27 provided results that invalidate the trade-off model's main assertion. In this point we  
28 agree with Skinner (1992; 1996) when he affirms that trade-offs, limitations and  
29 compromises are likely to always exist. We think that this single idea and argument is  
30 unlikely to be refuted.  
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## 41 **5. Conclusions and suggestions for future research**

42 In this paper, we have reviewed and critiqued the approaches and rationales  
43 used by studies that have aimed to test the validity of the trade-off model and its  
44 contending theories. To aid in the analysis, we introduced a framework differentiating  
45 between the measurement of industry level performance and internal organisational  
46 (plant) level performance. A review of the literature reveals the presence of important  
47 limitations and inconsistencies in the methodologies utilised in those investigations.  
48 For example, two of the most influential papers that claim to provide support for the  
49 cumulative capabilities models and against the trade-off model observe important  
50 difficulties that make their results and conclusions questionable. Recent studies that  
51 also affirm support of these alternative theoretical models contain similar issues. The  
52 adequacy of the data and methodologies that have been utilised in order to test these  
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3 models has been examined, and more correct and consistent approaches and  
4 methods have been recommended.  
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8 The trade-off concept and its competing theories have been at the centre of much  
9 research and debate over the past few decades. This is not surprising, as one of the  
10 core issues in the operations management literature is how manufacturing  
11 organisations can achieve high levels of performance that might provide them with a  
12 competitive edge. Having identified several and important issues in previous  
13 research, we now propose several guidelines for future studies that aim to test such  
14 theories and concepts:  
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- 21 • We propose that the term “cumulative capabilities models” or “cumulative  
22 models” should be used exclusively to denote those models that aim at  
23 explaining how cumulative and sequential internal improvements can lead to  
24 high performance levels on a number of capabilities. We think that our field  
25 will benefit more from the use of a precise, more consistent and specific  
26 terminology.  
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- 33 • The trade-off model is mainly concerned with performance analyses and  
34 comparisons from an industrial-marketplace perspective. Thus, when  
35 assessing manufacturing performance measures, and in terms of the trade-off  
36 model or its rival models, the main level of performance analysis should be  
37 measured towards an “external reference” (e.g.; performance compared to  
38 industry/competitors along quality, delivery), and not at an “internal reference”  
39 (i.e.; change of performance over time) level. As previously mentioned, these  
40 two types of measurements, if not properly distinguished, can potentially lead  
41 to very different and erroneous conclusions about the actual performance of  
42 an organisation. A framework which explains their differences and how to  
43 measure these two types of performances is offered in section 3.  
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- 51 • While the use of general regression/correlation analysis and related  
52 methodologies is useful to identify patterns and associations amongst  
53 variables, they are a limited approach to identify actual levels of performance  
54 achieved by firms. Hence, in addition to these methodologies, studies could  
55 also include analyses that clearly identify the firms that achieve an  
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3 outstanding enough performance across multiple criteria. This approach  
4 would be more consistent with the trade-off model's core principles.  
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- 10 • Quantitative studies have been a favoured approach to study the trade-off  
11 model and its competing theories. Therefore, more case studies, especially of  
12 the longitudinal nature that monitor the development of capabilities are  
13 needed. This would be a particularly adequate approach to test the sequential  
14 development of capabilities proposed by the cumulative models.  
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  - 17 • The underlying idea behind the cumulative capabilities models is that of  
18 sequential and incremental internal improvements (internal reference), which  
19 ultimately will result in the attainment of high levels of performance across a  
20 number of manufacturing performance measures (external reference). This  
21 has not been clearly stated and proposed in the past, so the following  
22 equation formally establishes these relationships:  
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30 High levels of performance in manufacturing performance measure "X" (external  
31 reference) = internal performance improvements in manufacturing performance  
32 measure "X" (internal reference) + internal performance improvements in the  
33 preceding manufacturing performance measures in the sequence proposed by the  
34 cumulative models (internal reference).  
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39 We think that a study such as the one proposed in the preceding equation  
40 would indicate whether the core ideas of the cumulative models are true.  
41 Moreover, since the dependent variables would be measured based on  
42 external references of performance, a comparison and evaluation against the  
43 trade-off model would be valid. To the best of our knowledge, the  
44 relationships depicted in the above equation have not been explored before.  
45 Consequently, future studies, apart from measuring each manufacturing area  
46 with respect to industry/competitors, could also take measures of internal  
47 change of performance over time for each of the same manufacturing areas.  
48 With these two types of measures available, a study that more faithfully  
49 models the cumulative capabilities concept can be put together.  
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The development and advancement of scientific theories have to be built in a  
specific and consistent way so that newer theories can improve on previous theories.

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3 Clearly, methodologies and variables, amongst other factors, have to be consistent  
4 with the core concepts and ideas of the theories that are to be evaluated. This paper  
5 has identified some of the inconsistencies and deficiencies observed in previous  
6 studies in operations strategy and performance evaluation research in operations  
7 management. We hope that future studies will benefit from these observations and  
8 proposals so that our understanding of the relevant themes and issues can be  
9 furthered.  
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19 **Professor Wickham Skinner which greatly improved the paper.**  
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**Table 1.** Manufacturing capabilities studies used to evaluate the trade-off model and/or the cumulative capabilities and rigid-flexibility models.

Authors	Methodology	Independent Variables ( <i>performance measurement reference</i> )	Dependent Variables ( <i>performance measurement reference</i> )	Main Conclusions
Grobler and Grubner (2006)	Path analysis	Quality, Time, Flexibility ( <i>internal reference</i> )	Time, flexibility, costs ( <i>internal reference</i> )	Found support for the sand cone model. Quality has to be considered as the base capability that supports other manufacturing capabilities.
da Silveira (2006)	Regression analysis	simplicity (pull production, e-commerce, process focus, etc), discipline (quality programs, TPM, etc)	mix flexibility, product customisation ability, time to market, volume flexibility ( <i>internal reference</i> )	Provide further empirical validation to the rigid-flexibility model.
Fynes et al (2005)	Path analysis	supply chain relationship dynamics (i.e. adaptation)	quality, costs, flexibility, delivery ( <i>external reference</i> )	Found only partial support for the sand cone model. Results are more aligned with trade-off theory
Narasimhan et al (2005)	Cluster analysis, categorisation, t-tests	JIT, SPC, AMT, Quality culture, ITD, COM	new product development, flexibility, efficiency, market-based performance ( <i>external reference</i> )	Proposes "capability progression theory"
Rosenzweig and Roth (2004)	Path analysis	conformance quality, delivery reliability, volume flexibility ( <i>external reference</i> )	delivery reliability, volume flexibility, low costs ( <i>external reference</i> ).	Found support for the cumulative capabilities model (competitive progression theory)
Lapre and Scudder (2004)	Regression analysis, categorisation	Quality (consumer complaints, <i>external reference</i> ), Costs (cost per available seat mile, <i>external reference</i> )	Quality (consumer complaints, <i>external reference</i> ), Costs (cost per available seat mile, <i>external reference</i> )	Firms that operate close to their asset frontiers face initial trade-offs. Lasting quality improvements precede lasting cost improvements.
Flynn and Flynn (2004)	Regression analysis	process-based quality, market-based quality, on-time delivery, fast delivery, cycle time, new product speed, product flexibility, volume flexibility, costs. ( <i>external reference</i> ). Supply chain management, quality management, lean manufacturing, etc. Industry, Country.	process-based quality, market-based quality, on-time delivery, fast delivery, cycle time, new product speed, product flexibility, volume flexibility, costs. ( <i>external reference</i> ).	Found support for cumulative capabilities, but not in the pattern proposed by the sand cone model
Rosenzweig et al (2003)	Regression analysis	supply chain integration intensity	product quality, delivery reliability, process flexibility, cost leadership. ( <i>external reference</i> )	High integration intensity lead to higher performance on product quality, delivery reliability, process flexibility and cost leadership
Corbett and Claridge (2002)	Categorisation, regression analysis.	Contextual variables (industry, country)	First pass yield, percentage of on-time deliveries, manufacturing cost as % of sales, average lead-time for new products, % of sales of new products ( <i>external reference</i> ).	Achieving high performance on many performance areas is difficult. Did not find support for the capabilities development sequence proposed by the sand cone model.
Corbett and Whybark (2001)	categorisation, t-tests	JIT systems, TQM, MRP, cellular manufacturing, SPC, factory automation, employee participation programs, amongst others.	Unit cost of manufacturing, quality of products, manufacturing speed, delivery speed, delivery as promised, product change flexibility, volume output flexibility, product design time ( <i>external reference</i> ).	Provides some evidence for the sand cone effect. A firm should invest first in quality practices and then add others to this base in order to achieve higher performance across various manufacturing areas.

da Silveira and Slack (2001)	Case studies	structural and infrastructural factors (technology, skills, managerial abilities, capacity, flexibility)	product quality, speed of delivery, dependability of delivery, product variety, manufacturing costs ( <b>external reference</b> ).	Trade-offs between different pairs of manufacturing areas are real and dynamic. Trade-offs can be improved, but not eliminated.
Dostaler (2000, 2001)	Categorisation, Case studies	Managerial, structural and infrastructural aspects.	Cost (annual productivity), quality (external defect rate), Dependability (late deliveries), Flexibility (modified orders) ( <b>external reference</b> ).	Commitment to quality improves productivity. Formalism, discipline and control will result in higher "flexibility". Key structural and infrastructural aspects also explain high performance.

Table 1. (Cont.)

Authors	Methodology	Independent Variables ( <i>performance measurement reference</i> )	Dependent Variables ( <i>performance measurement reference</i> )	Main Conclusions
Safizadeh et al (2000)	Factor analysis, correlation analysis	Process technology	Quality, Delivery, Costs, Customisation ( <b>external reference</b> )	Found evidence of trade-off between some, but not all pairs of performance. Relationships get sharper when controlling for process choice.
Mapes et al (2000)	Categorisation, t-tests	adherence to schedule, process time variability, delivery by suppliers, process output variability, throughput times, stock levels ( <b>external reference</b> )	Productivity, quality consistency, delivery reliability, customer lead times ( <b>external reference</b> )	High performing plants have a lesser degree of uncertainty and variability than low performing plants.
Fynes et al (2000)	Factor analysis and path analysis	Quality practices, Product costs ( <b>external reference</b> )	Quality performance, Product costs, New product development ( <b>external reference</b> )	Found partial support for the sand cone model.
Flynn et al (1999)	Factor analysis, correlation analysis, regression analysis, categorisation	World-class manufacturing practices (as proposed by Hayes & Wheelwright), Core quality practices, Core JIT practices.	Cost ( <b>internal reference</b> ), quality performance, quality features, dependability specifications, delivery reliability, product flexibility, volume flexibility ( <b>external reference</b> )	Combination of WCM practices, quality management practices and JIT practices lead to higher performance across a number of manufacturing areas, which goes against the trade-offs model.
Collins et al (1998)	Regression analysis, factor analysis	Simplicity (problem solving, supplier lead-times, supplier relations, kanban), Discipline (business process documentation, training, quality vision, defects, etc)	inventory management, warehousing, product cycle time, total cycle time, new product introduction, customer delivery time ( <b>external reference</b> )	Found no support for the trade-off or sand cone model. Evidence supported the "rigid-flexibility" model.
Filippini et al (1998)	Correlation analysis, categorisation	manufacturing systems, internal and external relations, conformance quality ( <b>external reference</b> )	return on sales, invested capital turnover, conformance quality, quality capability, delivery time, punctuality ( <b>external reference</b> ).	Found support for the sand cone model. High performance along several areas of manufacturing is possible, but also difficult.
Szwejczewski et al (1997)	t-test and correlation analysis.	Reduced defects, cellular manufacturing, reduced operational complexity	manufacturing lead-times, delivery performance ( <b>external reference</b> )	trade-off between lead-times and delivery performance no longer operates.
Morita and Flynn (1997)	categorisation, t-tests, correlation analysis.	Strategic adaptation, management practices, production control system, human resource development, commitment, amongst others.	Manufacturing costs, quality conformance, on-time delivery, production cycle time, NPI, product capability/performance ( <b>external reference</b> )	Provides some evidence for the cumulative performance model. Best practices implementation can lead to higher cumulative capabilities performance as predicted by the sand cone model.
Mapes et al (1997)	correlation analysis	internal "competences", product variety ( <b>external reference</b> ), new product introduction ( <b>external reference</b> )	manufacturing costs, quality consistency, lead time, delivery reliability, new product introduction, product variety ( <b>external reference</b> )	Trade-offs still exist, but other areas of manufacturing seem to be in a compatible situation.

Table 1. (Cont.)

Schroeder et al (1996)	regression analysis	cycle time, conformance quality, fast delivery, flexibility ( <i>external reference</i> )	cycle time, conformance quality, fast delivery, flexibility, on-time delivery, costs ( <i>external reference</i> )	Proposes the network theory of plant performance. Found support for the sand cone model. Conformance quality is the "driver" of a number of different capabilities.
Noble (1995)	t tests, categorisation, correlation and regression analysis	Quality ( <i>internal, external reference</i> ), Dependability ( <i>internal, external reference</i> ), Delivery ( <i>external reference</i> ), Costs ( <i>internal, external reference</i> ), Flexibility ( <i>internal, external reference</i> ), Innovation ( <i>external reference</i> )	Quality ( <i>internal, external reference</i> ), Dependability ( <i>internal, external reference</i> ), Delivery ( <i>external reference</i> ), Costs ( <i>internal, external reference</i> ), Flexibility ( <i>internal, external reference</i> ), Innovation ( <i>external reference</i> )	Found support for the sequential development of cumulative capabilities.
Roth and Miller (1990, 1992)	Categorisation, t-tests	Materials Flow-JIT, Advanced process technologies, Information systems, Quality management programs, Capacity upgrades, Restructuring, Total factor resource improvements.	Quality, Delivery, Price, Flexibility, Market Scope ( <i>external reference</i> )	Trade-off theory not supported within the "leaders" group. Evidence found for the cumulative theory of capabilities development.
Ferdows and de Meyer (1990)	Correlation analysis, categorisation	JIT, SPC, quality circles, FMS, Zero defects, etc.	conformance quality, unit production costs, inventory turnover, development speed, on-time delivery, delivery speed, overhead costs. ( <i>internal reference</i> )	Propose the development of sequential, cumulative capabilities (sand cone model).

**FIGURE 1**

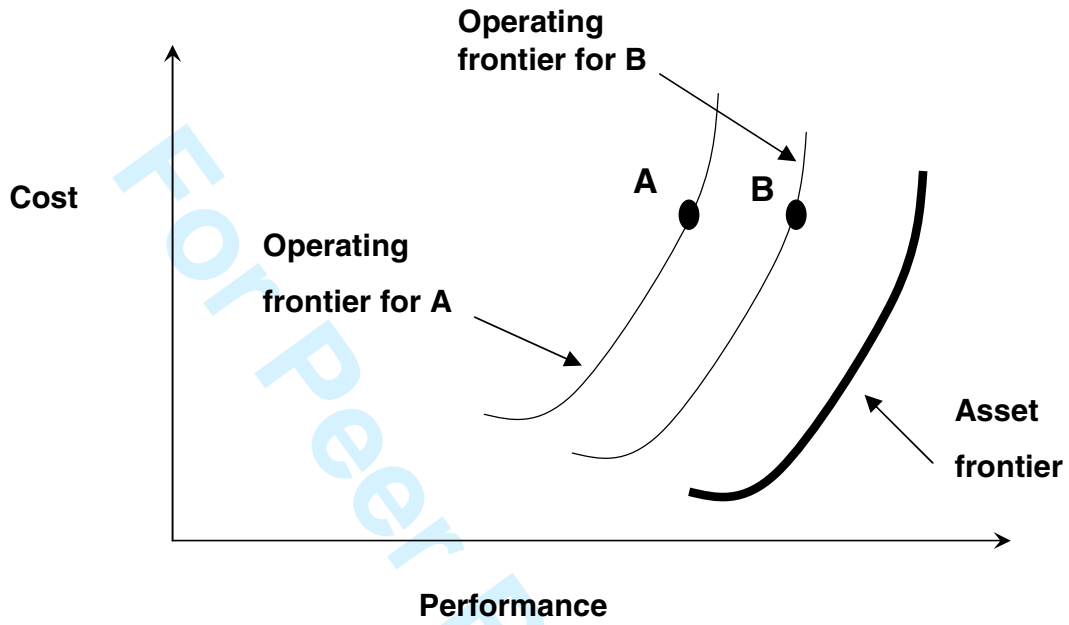
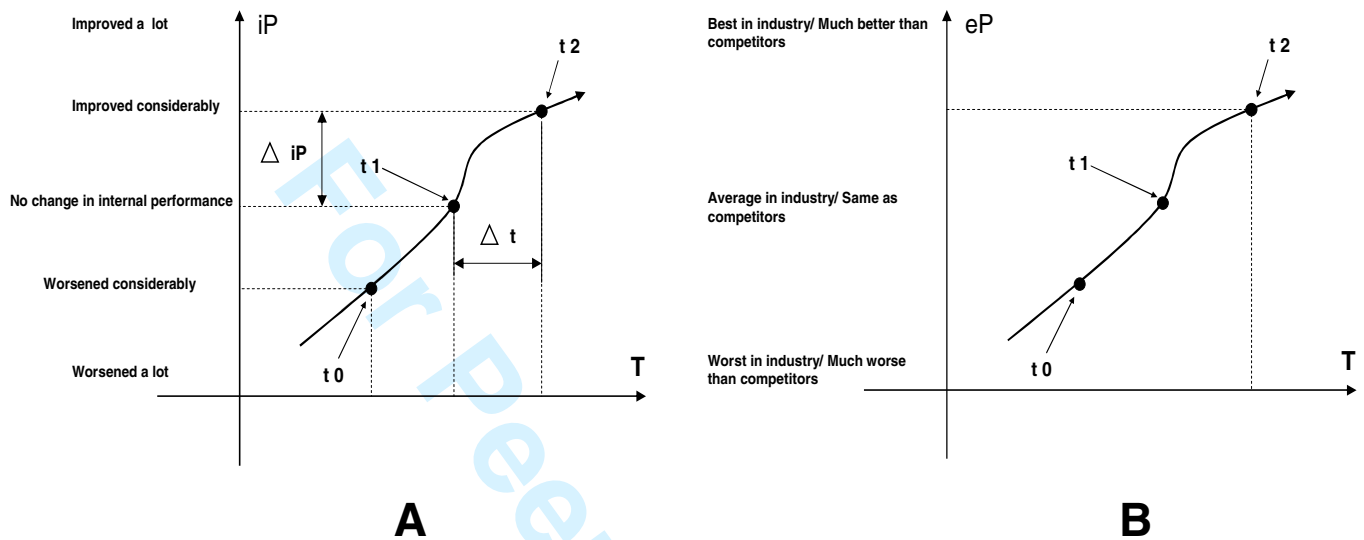


Figure 1. Operating and asset frontiers. Firm A is likely to operate under the laws of cumulative capabilities while firm B, due to diminishing returns on improvement is more likely to be subject to the law of trade-offs. (adapted from Schmenner and Swink, 1998).



**FIGURE 2 A & B**

**Figure 2 A & B. Framework for performance measurement in relation to internal changes over time and in relation to competitors- industry.**