Information Systems Frontiers – (accepted Oct, 2016)

The Impact of Big Data Analytics on Firms High Value Business Performance

Ales Popovic
University of Ljubljana, Slovenia

Ray Hackney
Brunel University London, UK

Rana Tassabehji
Bradford University, UK

Mario Castelli
NOVA IMS, Portugal

Abstract: Big Data Analytics (BDA) is an emerging phenomenon with the reported potential to transform how firms manage and enhance high value businesses performance. The purpose of our study is to investigate the impact of BDA on operations management in the manufacturing sector, which is an acknowledged infrequently researched context. Using an interpretive qualitative approach, this empirical study leverages a comparative case study of **three** manufacturing companies with varying levels of BDA usage (experimental, moderate and heavy). The information technology (IT) business value literature and a resource based view informed the development of our research propositions and the conceptual framework that illuminated the relationships between BDA capability and organizational readiness and design.

Our findings indicate that BDA capability (in terms of data sourcing, access, integration, and delivery, analytical capabilities, and people's expertise) along with organizational readiness and design factors (such as BDA strategy, top management support, financial resources, and employee engagement) facilitated better utilization of BDA in manufacturing decision making, and thus enhanced high value business performance. Our results also highlight important managerial implications related to the impact of BDA on empowerment of employees, and how BDA can be integrated into organizations to augment rather than replace management capabilities. Our research will be of benefit to academics and practitioners in further aiding our understanding of BDA utilization in transforming operations and production management. It adds to the body of limited empirically based knowledge by highlighting the real business value resulting from applying BDA in manufacturing firms and thus encouraging beneficial economic societal changes.

Keywords: Big data analytics, Business value, Operations performance, Case analysis

1. Introduction

Within the current turbulent and highly competitive global environments, firms are compelled to adapt more rapidly, boldly, and to experiment in order to survive and thrive. They are increasingly seeking ways to identify the constraints in advancing business processes which severely hampers their ability to respond to accelerating competitive demands. Extant studies, thus, advise firms to focus on the development of organizational agility (Chakravarty et al., 2013, Tallon and Pinsonneault, 2011, Bi et al., 2013), which, in turn, enables them to respond to a wide variety of environmental business changes in an appropriate and timely way. The characteristics of agility are that firms, while continuously identifying and developing new advantages, orchestrate their business processes in a way to enable them to explore new opportunities effectively as well as to exploit those opportunities efficiently, to improve firm performance (Chakravarty et al., 2013).

The potential of information systems (IS) to inform decision making and improve firm performance has long been emphasized in the information technology (IT) business value literature (Davern and Kauffman, 2000, Mithas et al., 2011, Melville et al., 2004, Bhattacharya et al., 2010). In firm performance studies, IS have been reported to support timely decisions, provide insights that increase comparative advantage, promote innovation, and offer a means to manage environmental uncertainty (Popovič et al., 2014). Consequently, firms rely on their IS for the provision of high quality information, i.e. information that is relevant, reliable, accurate, and timely (Popovič et al., 2012, Wixom and Todd, 2005), that facilitates improvements in decision quality and can, in turn, elevate firm performance (Mithas et al., 2011). To leverage the benefits of insightful information, firms are thus increasingly investing in various technologies and embedding them into their business processes (Chen et al., 2012).

The hypercompetitive aspects of modern business environments have drawn firm attention toward agility as a strategic capability where IT-enabled information is expected to have an important role in the development of organizational capabilities (Chakravarty et al., 2013). A form of organizational agility that is of particular relevance to research is *process agility*, or the extent to which firms can easily and quickly retool their processes to adapt to the market environment (Chen et al., 2014). In particular, data-driven business analytics are regularly emphasized as a foundation for innovation and agility in current business environment (Chen and Siau, 2011, Davenport et al., 2012, Kiron et al., 2012).

Business intelligence and analytics and the related field of big data analytics (BDA) have become increasingly important in both the academic and the business communities over the past years (Chen et al., 2012). From the academic perspective, big data research has attracted attention at the level of widely read scientific outlets such as *Proceedings of the National Academy of Sciences* and *Science* because of the importance and generic nature of the inquiries (Agarwal and Dhar, 2014). Also, firms are constantly trying to draw insights from

the expanding volume, variety, and velocity of data to make better sense of the data and to improve decision making (LaValle et al., 2011). In addition to interpreting ways to address known problems, firms are focusing on identifying trends that they did not know before (Fosso Wamba et al., 2015). The opportunities associated with data and analysis in different organizations have helped generate significant interest in BDA, which is often referred to as the techniques, technologies, systems, practices, methodologies, and applications that analyze great variety of critical business data to help a firm better understand its business and market, and make timely business decisions (Gandomi and Haider, 2015, McAfee and Brynjolfsson, 2012). With an overwhelming amount of web-based, mobile, and sensor-generated data arriving at huge scale, novel insights can be obtained from the highly detailed, contextualized, and rich contents of relevance to any firm or organization (Agarwal and Dhar, 2014, Chen et al., 2012). According to a recent survey from MIT Sloan Management Review and IBM of more than 3,000 business executives, managers, and analysts from organizations located around the world, "top-performing organizations use analytics five times more than lower performers" (LaValle et al., 2011).

In operations management, the application of BDA is particularly important in supporting operational and strategic decision-making, and enhancing performance (Kiron et al., 2014). However, scholars argue that leveraging performance benefits depends less on having the technology and more on being able to make the best use of new insights in advancing organizational agility (Kretzer et al., 2014). Insights from BDA have the potential to enable real-time business process monitoring and measurement, enhancing quality management (Waller and Fawcett, 2013, Davenport et al., 2012), reinforcing customer relationships, managing operations risks, improving operational efficiency and effectiveness, or to improve product or service delivery (Kiron, 2013, Zelbst et al., 2011).

While prior research has suggested BDA usage and IT infrastructure flexibility are two important sources for an organization's agility (Chen and Siau, 2011), our understanding of the processes and factors enabling, facilitating, or impeding successful utilization of BDA in operations, remains limited. Emphasis is, therefore, increasingly placed on the underlying mechanisms that link BDA to operations' agility. To address this gap, we conducted a comparative case study of three manufacturing firms that utilize big data analytical capabilities in their operations. We explored what a firm must do right in order to utilize its big data analytical capabilities so as to fully leverage the value of BDA in enabling the improvements of its operations?

The remainder of this paper is organized as follows. We first set out the conceptual background of our research. We then outline the research approach and introduce the three case firms, outline the sources of data and explain our data analysis procedure. This is followed by our findings on how the utilization of BDA affects organizational agility and the underlying mechanisms that link BDA to improvements in operations performance. In the

discussion section, we explore the contributions and practical implications of our findings. Finally, some inherent limitations and avenues for future research are given.

2. BDA: Conceptual Development

Business agility is the ability to adapt and alter businesses and business processes to effectively manage unpredictable external and internal changes quickly and easily (Oosterhout et al., 2006). Much of the drive to achieve agility has come from IT vendors and consultancies such as IBM presenting "big data" as a solution. Data analysis has been used to improve the performance of firms for over a decade where immature systems for management of data was considered to be a limiting factor to further improving business performance (Sackett and Bryan, 1998). A framework for the development of data management systems to improve manufacturing processes was highlighted by Sackett and Bryan (1998). The building blocks of their framework are helpful in this context as there is a clear link between data related to the manufacturing process, implementation and use of systems that manage and process the data and the needs of the organization. They warn that any technology solutions must be business requirements driven and identify (a) system capabilities including its features and functionality (b) financial and human resources required (c) incorporating business requirements and organization-wide implementation plans including intra organizational co-operation that reflect the organization's strategic objectives as core building blocks. The advent of BDA, means that there are some major differences in terms of the types of data and how this can be processed to benefit organizations (McAfee and Brynjolffson, 2012). Namely, that the sheer volume of data, the speed at which it is created and the different sources from which it is collated means that more can be done with analytical techniques to draw value from this data. We contribute to the business value of IT literature by unpacking how the utilization of BDA changes manufacturing operations towards improvements in performance. Figure 1 presents a framework identifying BDA systems and organizational factors that impact implementation of BDA system and ultimately organizational performance, in this case manufacturing.

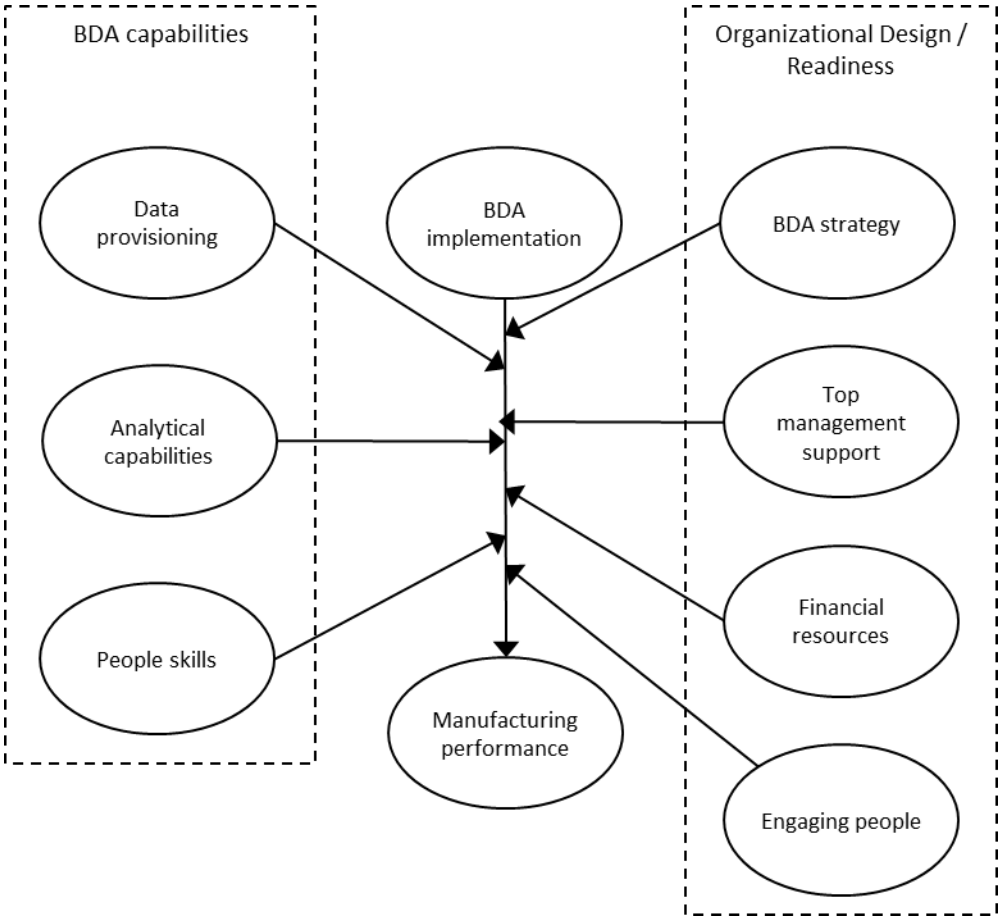

Figure 1: BDA Performance Factors

Consistent with our outline theoretical stance on decision making and resource-based perspectives, our study makes two contributions. First, we show that utilization of BDA in manufacturing operations can enhance manufacturing performance. The shift toward BDA-supported performance indicators enables decision makers to utilize additional data in considering different courses of action when pursuing set goals. Echoing extant studies in operations literature, we find that when firms utilize more BDA, they better forecast previously unpredictable outcomes, and improve process performance. As a result, firms realize operational process benefits in the form of cost reductions, better operations planning, lower inventory levels, better organization of the labor force and elimination of waste, while they leverage improvements in operations effectiveness and customer service.

Second, drawing on resource-based logic (Ray et al, 2005), we argue that such improvements in manufacturing operations, driven by increased utilization of BDA, can foster differential performance impacts (Hvolby & Steger-Jensen, 2010). However, we warn scholars and practitioners that a firm's BDA capabilities (in terms of Data sourcing, access, integration, and delivery, analytical capabilities, and people) and organizational factors (such as BDA strategy, top management support, financial resources, and engaging people) can facilitate (or inhibit) effective utilization of BDA in operations, and thus moderate differential performance benefits of BDA utilization. As such, we extend the IT business value literature, which argues

that seeking strategic advantage merely by developing IT capability may not necessarily realize enhanced performance; organizational design/ readiness factors are critical for effective IT utilization (Hong & Kim, 2002; Dezdar & Sulaiman, 2011).

3. Methodology

Research sites and data collection

Due to the early stages of research on how BDA may transform operations and improve performance and the significant lack of empirical analysis within the context of manufacturing, we adopted an exploratory case study method (Benbasat et al., 1987). Case studies provide a source of well-grounded, rich descriptions and explanations of developments that are relatively weakly understood (Miles et al., 2014). In our study, we employed a multi-case design that supports a replication logic, through which a set of cases are treated as a series of experiments, each serving to confirm or disconfirm a set of observations (Yin, 2014).

We carried out our research in large manufacturing firms, as this sector has proven well suited to study the benefits of BDA implementation (Lee et al., 2013, Auschitzky et al., 2014) as the use of analytics for product development, operations and logistics is increasing (Dutta and Bose, 2015). The BDA revolution has set the stage for the use of large data sets to predict future events and actions (e.g. resource failure, adaptation of manufacturing operations) by taking into account the real-time outcomes of complex and unexpected events (Babiceanu and Seker, 2015). The three case firms selected have all implemented BDA within a year apart, which fits in with our research focus (Eisenhardt, 1989). In their respective markets, each firm is ranked among the top performers in terms of annual revenues and number of employees. While we sought firms with similarities that would aid comparisons and replication, we also looked for sufficient heterogeneity to help assess potential generalizability. Table 1 provides relevant details about the three firms in our study.

Table 1: Overview of the Case Firms

Firm	Year founded	Manufactured goods (primary products)	Number of employees	Annual Revenue	Year when BDA was implemented
Firm A	1958	Buildings materials and construction systems	422	105.6 million €	Partially in 2012, finalized in 2013
Firm B	1954	Prescription pharmaceuticals, non-prescription products and animal health products	4,607	664.6 million €	Early 2014
Firm C	1950	Home appliances	4,112	1,116.3 million €	2014

Source: Agency for Public Legal Records and Related Services; data obtained from 2013 Audited Annual Report database.

We conducted our research using semi-structured interviews with a total of 13 employees who were directly (e.g., head of operations, warehouse supervisors) and indirectly (sales managers)

involved in the manufacturing process. The experience of participating respondents related to their years working in the industry and the time working for the firm presented in Table 2. Interviews were conducted from September to November 2014 and lasted around 1 to 2 hours. Interviews were audio recorded and transcribed with permission of the respondents. The study was longitudinal in respect that the individuals interviewed had insights of the organization before and after the adoption of BDA and were able to make comparisons and provide information about their experiences.

Table 2: Respondents' Characteristics

Firm	Respondents	Years in the industry	Years working for the firm
Firm A	Sales Manager	8	6
	Head of Research Operations	11	8
	Lead Operator for the Packaging Operations	7	5
	Warehouse Supervisor	6	3
Firm B	Market Sales Leader	10	7
	Manufacturing Specialist	8	4
	Head of Research and Development	15	14
	Supervisor of Process Automation	13	13
	Diagnostic Laboratory Specialist	5	5
Firm C	Regional Sales Manager	12	7
	Technical Production Manager	16	16
	Chief Project Leader	7	3
	Warehouse Supervisor	9	9

Data analysis

The data analysis process, following Miles et al. (2014), was systematic and iterative, where comparisons of data, emerging categories and existing literature aided the process. We first compiled separate case studies of each firm. We identified patterns and variance in descriptions of how utilization of BDA supports operations and examined the underlying mechanisms that linked BDA to improvements in operations' agility. To assess the reliability of the generated open codes, we then involved a second coder, with substantial qualitative research experience.

Next, we linked related concepts within each case. During this phase, we examined all conclusions derived from the initial coding and established links between and among previously stated categories. We allowed concepts and patterns to emerge based on the primary data collected, while new categories were added and others were regrouped with further analysis (Cassell and Symon, 1994). To improve generalizability (Firestone and Herriott, 1983), as well as to deepen understanding and explanation (Miles et al., 2014), we then compared each category and its properties across cases. Our main objective was to compare and contrast changes in the operations of the three case firms. To evaluate the reliability of each dimension, we first involved the second coder. All disagreements were

resolved through discussion. Second, we shared the results of the initial analysis with key respondents within the three case firms and with an independent professional in the field to assess plausibility of the conclusions reached. In the last stage we connected emergent themes and ideas with the concepts from the literature. Our data analysis moved back and forth between the emerging themes and extant literature to explore broadly possible explanations for our findings and enable focus on the justification that best fit with the data (i.e. explanation building) (Yin, 2012).

In the following section we discuss our findings. We first reveal how the introduction and utilization of BDA has transformed operations in the three case firms. Second, we uncover the underlying mechanisms that link BDA to improvements in operations.

4. Findings

Changes in operations with the utilization of BDA

In response to our research question, we examined how the introduction and utilization of BDA has transformed operations in the three case firms. We asked each of the three case firms how they had utilized BDA to support a wide range of performance aspects in relation to: (a) Planning - namely schedule and cost variance, capacity utilization (b) Manufacturing process namely process downtime, machine efficiency, waste reduction and (c) Quality assurance namely defective units, rejected units.

These were used as KPIs for assessing operations' performance and a more detailed explanation of these indicators is summarized in Table 3. In addition, we asked each of the three case firms to highlight the value achieved from utilizing BDA for each of the KPIs and the potential performance benefits they had experienced. The performance benefits focused around 3 major themes, ***Production time*** which was considered to be the actual time taken to manufacture; ***Operating expenses*** which determined the effectiveness of the firm in keeping operating cost in control and Customer satisfaction considered to be the customers' overall satisfaction regarding the firm's product, quality of the product, and level of customer service. These responses were noted and are compiled in summarized in Table 3. Not all firms experienced the same benefits, but consistently, across the three cases, the respective respondents suggested that the utilization of BDA had provided additional performance benefits that had improved their performance indicators across these areas.

Table 3: Assessing Firms' Operations Performance and the Support from BDA

KPIs for assessing operations' performance	Explanation of the indicator	Value from utilizing BDA	Potential performance benefits	Firm A	Firm B	Firm C
Planning						
Schedule and cost variance	Extent to which a firm is capable of delivering on schedule and within budget.	Better planning due to more comprehensive information; providing accurate estimates of order-to-delivery times	Customer satisfaction; Operating expenses			✓
Capacity utilization	Extent to which a firm is using its production potential.	Improved prediction of daily demand fluctuation; Better prediction of "black swans"	Operating expenses	✓	✓	✓
Manufacturing						
Process downtime	Extent to which the production process is available and running.	Predicting potential interruptions in process execution	Production time; Operating expenses	✓		✓
Machine efficiency	Extent to which a particular type of equipment was used during the production time.	Maximized equipment uptime by minimizing maintenance and preventing breakdowns	Production time	✓		✓
Waste reduction	Level to which a firm is able to reduce the waste it is generating as part of its operations.	Reduce manufacturing waste to optimize production - lean	Operating expenses	✓	✓	✓
Quality Assurance						
Defective units	Number of units produced by the firm that had defects compared to the total units produced.	Insights into factors leading to faulty products	Operating expenses	✓		✓
Rejected units	Number of units produced by the firm that were returned by the customer.	Preventing returns and rework; keeping firm image high	Operating expenses; Customer satisfaction		✓	✓

Our findings also revealed that the value of BDA utilization in different phases of manufacturing operations was wider in Firm C, than in Firms A and B (Table 3). Based upon the utilization of BDA across different phases of manufacturing operations, we can classify our case firms as: 1) experimental user (Firm B), where BDA use is mainly at the planning phase, seldom during the manufacturing and quality assurance phases; 2) moderate user (Firm A), where the firm uses BDA within manufacturing phase, occasionally also in planning and quality assurance; 3) heavy user (Firm C), where BDA is employed regularly across all phases, from planning to quality assurance.

Within the planning phase, all three firms utilize BDA for improving their capacity utilization despite the frequency of their usage. For instance,

> *Production volumes fluctuate daily – one day there is a lot to make, the next day there is hardly anything. Due to irregular demand, we can't predict it very well, and as a result we end up with unused capacity. Through utilization of BDA we learnt that these fluctuations in demand are not random. They depend on a large number of external factors, such as holidays, product launches, local/national incentives and the like.* Firm A's Lead Operator Packaging Operations (moderate user)

> Another (Firm B's Supervisor of Process Automation) elaborated: *As we have warehousing limitations, we use very detailed short-term forecasting (2-4 weeks) where we "grasp" any available information from the markets (e.g. competitors' pricing deals, delays in material delivery, political signals from distant markets, production-relevant information for parts directly provided by our suppliers) to have a better chance of predicting rather rare, but yet high impact events that might seriously influence our production/warehousing operations.* (experimental user)

> Firm C's Regional Sales Manager expanded on their utilization of BDA in the planning phase to further predict whether they are capable of delivering on schedule and within budget: *Schedule and cost planning are always two important issues we try to address with highest priority when starting a production of a particular product. On the one hand, accurate planning provides us an effective way to estimate the economic value. On the other hand, particularly concerning the delivery of goods to the customer, it increases the satisfaction of our customers. Through more comprehensive information, BDA enable us to include previously unconsidered events (e.g. cross-demand) that put a burden on our production line and resulted in not being able to meet set deadlines and costs* (heavy user).

Within the planning phase, both Firms A (moderate user) and C (heavy user) utilized BDA to minimize process downtime, maximize equipment efficiency, and reduce production waste. Firm's A Head of Research Operations noted:

Our manufacturing line has sensors attached to production assets (e.g. assembly machines, transport bells etc.) that send continuous streams of data about the assets' operational conditions to a monitoring station that then analyses them in real-time and detects any problems in the behavior or state of the asset. Once a problem is detected, a preconfigured action is taken to notify the operator or take corrective action. Thus, the potential unavailability of the production process is brought to its minimum.

Firm C's Technical Production Manager highlighted their experiences:

With our new solution we are monitoring and predicting potential equipment faults, to avoid or curtail process downtime or to help prevent faults reoccurring. Specifically implemented sensors are preventing process downtime by detecting changes in inputs and equipment functioning that could be caused by unobservable conditions. If left undetected, these changes cannot only affect individual equipment utilization but bring whole process down.

His colleague (Chief Project Leader) further emphasized: *Besides aiming at having our capacities fully utilized, our goal was to have as many machines as possible operating 24/7. To achieve this, the machines had to be closely monitored and undertake proactive maintenance. With the ability to closely monitor machines' technical data in real-time (e.g. temperature, pressure, power, and other sensor readings) enabled us to better plan for maintenance and prevent machines from suffering frequent breakdowns*.

In contrast, Firm B's (experimental user) manufacturing phase focus was less on improving availability and equipment efficiency (direct process aspects) but more on reducing waste (direct cost aspects):

Our company has long discovered that production resource waste is a significant factor in operations costs. In fact, with the implementation of BDA solutions we gradually became able to reduce the utilization of materials (10-15%), reduce energy (about 5%), reduce scrap and rework (about 15%), as well as reduce manual labor (about 20%) (Manufacturing Specialist).

Nevertheless, all three case firms highlighted the quality assurance phase as important predictors of customer satisfaction and the firms' operating expenses, as being important to their operations. As such, Firm A (moderate user) was able to gain better insights into factors leading to faulty products, while firm B (experimental user) was able to further reduce returns and rework, keeping firm image high. A Warehouse Supervisor in Firm A noted:

It is inherent to the production process to face defects. With the implementation of BDA we gained an additional layer of filtering during the inspection process which

enabled us to improve confidence in identifying defective products. Data, such us production line environmental conditions, operators, task where failures occurred, time/season of failures, material suppliers, lot numbers, helped us better understand the reasons behind defects and make more educated guesses about faulty items before they were dispatched to the customer.

A Market Sales Leader from Firm B explained that:

While defective units identified during the production typically result in sunk costs or rework costs, an even greater problem is when these units pass our control mechanisms unnoticed and make it to the customer. Thus, dismissing potentially problematic items through the utilization of predictive analytics improves rejection rate by 8-10%, saving us from additional costs and worsening firm reputation.

While Firm C, the heavy user of BDA, was able to tackle both issues through BDA utilization.

Moreover, heavy use of BDA endorsed informed decision making and transformed extant organizational capabilities. Our findings suggested that the more widely the case firms utilized BDA, the more they improved decision making in manufacturing operations, resulting in added benefits for all partners involved (customers, firms themselves). Across the cases, respondents stressed that BDA was pivotal in promoting employee empowerment, fact-based and real-time decision making, as well as promoting proactive actions that enabled improvements in performance management, functional area excellence, and value proposition enhancements.

Table 4: Manufacturing Operations Before and After BDA Implementation

	Firm A – moderate user		Firm B – experimental user		Firm C – heavy user	
	Before BDA implementation	After BDA implementation	Before BDA implementation	After BDA implementation	Before BDA implementation	After BDA implementation
Decision making						
Power shifts (empowering employees so that they can take initiative and make decisions to solve problems and improve performance)		✓			✓	✓
Fact-based decision making (relying on a consideration of operations-related facts when making decisions)	✓	✓	✓	✓	✓	✓
Real-time decision making (making changes in the execution of the process based on real-time events)		✓				✓
Proactive vs. reactive actions (actions are not only made as corrective response to events but also as preventive activities)		✓		✓		✓
Organizational capabilities						
Improved performance management (financial reporting, performance measurement, dashboards for management reporting)		✓		✓	✓	✓
Functional area excellence	✓	✓			✓	✓
Value proposition enhancement						✓

Estimates provided by the case informants during the interviews.

Before BDA adoption, in all three firms, the ability to transform decision making and organizational capabilities was limited, but after BDA adoption these abilities improved considerably. Detailed descriptions are available in Table 4.

Respondents from heavy and moderate user of BDA (firms A and C) emphasized how empowerment of employees in relation to managing the production phases was significantly transformed. The Head of Operations from Firm A explained the situation before BDA implementation:

> *People had rather limited powers regarding reconfiguring the production process as a result of changes in the environment. Everything had to be approved by their supervisors, particularly additional information from other sources about the event in question was regularly requested. Through the availability of more detailed, up-to-date data, and new insights these approvals were not needed as much, and as employees were given the power to make several decisions (e.g. requesting maintenance, changes in execution etc.) on their own*.

A Warehouse Supervisor from Firm C reinforced this point:

> *If anything unplanned happens in the process, we immediately take corrective actions to limit the potential future negative outcomes. We have the power to do so as well as to decide – since now we have a more comprehensive view of the reasons leading to the event – how to reconfigure our operations in the next few hours after the event that are the most crucial as they bring the greatest variability in our established procedures*.

Such shifts in power enabling more employees to make fact-based decisions were consistently observed across all case firms. There was also a shift toward more real-time decision making (Firm A and C), as well as a shift from taking reactive actions to unplanned events to a more proactive approach following activities experienced by all case firms. A Market Sales Leader from Firm B elaborated:

> *Our previous pricing models included some estimated cost categories that could not be fully given a value to. With BDA, this has changed in a sense that now we have better, more reliable information about the potential costs that we can readily include in our price estimates. As the business environment is getting more and more competitive, cost-effectiveness – both planned and achieved – is very important in our field.*
>
> A Regional Sales Manager from Firm C added: *We owe it to our customers and ourselves. To the former, we are obliged as good partners to provide an honest value for their money, to ourselves, we are required to know how much can we "stretch" in price competitiveness.*

Real-time and proactive decision-making has been a major benefit to the case firms.

> *In our process, timely responses to production events are crucial. I believe every major manufacturing firm agrees. If we see a problem coming, and now we can frequently even spot it before it occurs, the consequences (both financial as process-related) can be controlled. For example, when a specific machine is about to give up, several events are there that once carefully analyzed, can help us pinpoint the breakdown with a time window with 70-80% probability. This is a huge help for us to immediately steer the activities to solve the issues before they become serious problems.* Supervisor of Process Automation Firm B

> *We always wished we had a crystal ball – many of our problems resulted from being unable to adequately address what the data has been saying in time before the problem happened. In fact, with the investment into this new technology* [referring to BDA] *we reduced our maintenance and waste costs for about 12,5% on a year-to-year basis.* Chief Project Leader, Firm C

Moreover, various organizational capabilities were also found to have been improved through BDA implementation and use.

> *The new tools we have significantly added to the way we manage our manufacturing performance. We now have real-time updating reports, with possibility to dig deeper into root causes of lower-performing tasks, exception analysis, as well as what-if analysis. The informative dashboards, fuelled with huge variety of data, help us focus on important performance indicator more quickly.* Lead Operator for Packaging Operations & Warehouse Supervisor, Firm A

> *Now I have a better overall picture about the process/activity times, maintenance periods, waste and quality control throughout every production phase. The link between performance indicators across these phases is conveniently implemented for those of us who are responsible to make decisions.* Yet, not only internal performance, but also functional area excellence and value proposition were enhanced. A Regional Sales Manager from Firm C noted: *Throughout constantly monitoring and correcting the process we are able to provide our customers a high-quality product, delivered on time, and with all agreed characteristics. While our customers don't really know what is happening in the "production black box" of our firm, they perceive our efforts as being the acceptable reason for price premiums we charge.* Chief Project Leader, Firm C

> *Each functional area within our firm has a role to play both in the implementation of the strategy but also in the design and selection of the strategy. Each functional area, also manufacturing, has its own strategy which 'feeds into' the corporate strategy. This strategy sets out the plan for how manufacturing is going to do its part to make the*

corporate strategy a success. With BDA we are able to make a cleared contribution in terms of feasibility of achieving a high product quality levels as emphasized in our corporate strategy. Sales Manager, Firm A

Initially, Firm C appeared to have the most advanced BDA capabilities in place to mobilize the best use of BDA and enjoy the most performance benefits. In particular, compared with Firms A and B, Firm C worked on the full access to data from various sources, offering an integrative view of the operations, and timely delivery of mission critical information to the right people. Both Firms B and C implemented adequate tools for a historical view of business performance (e.g. standard reporting, ad-hoc reporting, query and drill down), descriptive analytics (e.g. statistical analysis, sensitivity analysis), and dynamic, predictive insights (e.g. optimization, simulation, predictive modelling) and visualization. Firm C also leveraged employee expertise to identify and prioritize the problems worth solving.

Moreover, organizational factors seem to have facilitated better utilization of BDA or subdued its benefits among the case firms. In Firm C, for instance, they developed a BDA strategy as a blueprint for BDA implementation. A Chief Project Leader from Firm C recalled: *BDA strategy preceded our BDA implementation in manufacturing process. We invested considerable effort into to establish our operations business vision and identify the supporting BDA capabilities required to achieve this.* Moreover, while top management only partially supported BDA initiatives in Firm A and B, within Firm C BDA implementation was fully supported by top management. A Warehouse Supervisor from Firm C noted: *As our operations are closely tied to costs and customer satisfaction, our executive level firmly believes we need good information from each of the production phases as to better estimate production times and costs, capacity utilization, prevent potential downtimes, reduce waste and secure appropriate quality.*

In addition, effective BDA utilization was also linked to financial resources and the level of employee engagement in the project, in Firm C,. A Chief Project Leader in Firm C argued: *The budget to fully introduce BDA was carefully planned for and secured in yearly financial planning. We managed to keep the project within the budget. During the implementation project regular meetings were organized where employees (managers, specialists etc.) were informed about the new capabilities as well as actively participated in the adjustments that needed to be carried out to fine-tune the operations.* Whereas the Head of Research Operations from Firm A recalled: *A specific budget was not allotted and the firm had limited financial resources. We had reserved the funds for this investment, yet, these were limited as the firm was restricting new IT investment funding.*

Table 5 provides a summary of the benefits for the three case firms from the utilization of BDA in their manufacturing operations.

Table 5: Benefits from the Utilization of BDA in Manufacturing Operations

	Firm A –	Firm B –	Firm C –

	moderate user	experimental user	heavy user
More accurate estimation of product delivery times and budget		✓	✓
Improved prediction of unplanned events	✓		✓
Maximization of equipment uptime through minimization of maintenance times and breakdowns	✓		✓
Reduction of production waste	✓	✓	✓
Minimization of returned products due to poor quality	✓		✓
Accurate, comprehensive and real-time information through informative dashboards		✓	✓

Overall, our findings illustrate that the introduction and utilization of BDA leveraged better insights in fundamental aspects of manufacturing operations, resulting in added benefits for all our case firms. We therefore posit the following:

Proposition 1: Implementation of BDA added novel insights to key performance areas of manufacturing operations.

Proposition 2: Distinct BDA-enabled capabilities and organizational design/readiness factors moderate the relationship between BDA implementation and operations performance.

Table 6: Firm Differences in BDA Capabilities

	Firm A – moderate user	Firm B – experimental user	Firm C – heavy user
Data sourcing, access, integration, and delivery	The access to data from various sources is fully available, offering an integrative view of the operations, and delivery of mission critical information to the right people is also timely.	The firm has access to all its operations-relevant data sources, yet, integration of such data only occurs at certain parts of the process, with delivery not always being consistent.	The access to data from various sources is fully available, offering an integrative view of the operations, and delivery of mission critical information to the right people is also timely.
Analytical capabilities	Adequate tools for historical view of business performance (e.g. standard reporting, ad-hoc reporting), descriptive analytics (e.g. statistical analysis, sensitivity analysis), and dynamic, predictive insights (e.g. optimization, simulation, predictive modelling) are available.	Adequate tools for historical view of business performance (e.g. standard reporting, ad-hoc reporting) and descriptive analytics (statistical analysis) are available. Among more advanced capabilities optimization and simulation tools are also available.	Adequate tools for historical view of business performance (e.g. standard reporting, ad-hoc reporting, query and drill down), descriptive analytics (e.g. statistical analysis, sensitivity analysis), and dynamic, predictive insights (e.g. optimization, simulation, predictive modelling) and visualization are available.
People's expertise	Since BDA implementation considerable attention was paid to secure a team of experts that provide statistics expertise, business perspective and technical expertise to the analysis of data and identified patterns. When appropriate skills were missing, the firm readily consulted field experts to fill the gap.	There are not many people with appropriate skills and expertise. While the firm has enough technical specialists, it lacks data and business analysts to bring sense to the data and provide relevance to identified patterns.	To provide expertise in statistics the firm has 2 data scientists on board, to identify and prioritize the problems worth solving and the business relevance of data anomalies and patterns identified by the data scientists business analysts are in charge, whereas for managing IT solutions needed to collect, clean and process data the firm relies on technical specialists' expertise.

Source: Interview transcripts.

Table 7: Firm Differences in Organizational Design/Readiness

	Firm A – moderate user	Firm B – experimental user	Firm C – heavy user
BDA strategy	While there was no explicitly formed strategy, there was a common understanding about the need to at least carefully think what the firm wanted to achieve with BDA and how. *We were eager to try the new technology, yet, several project implementation group members tried to "slow down" things a bit in order to give some deeper thought about what we want and where we want to be in the next 3-5 years with our BDA.*	There is no BDA strategy. BDA strategy was seen as an unnecessary waste of resources. *We have no BDA strategy in place, nor have we thought of needing one.*	The firm developed a BDA strategy as a blueprint for BDA implementation. *BDA strategy preceded our BDA implementation in manufacturing process. We invested considerable effort into to establish our operations business vision and identify the supporting BDA capabilities required to achieve this.*
Top management support	BDA implementation was partially supported by top management. *The prevailing opinion was that we needed better insights into our operations, particularly for predicting unfavorable future outcomes within our production process, yet, I still believe that we could also go by reasonably well without them.*	BDA implementation was partially supported by top management. *The current operation functioned well, we did not have much downtime, complaints, or frequently under-utilized capacities. In this sense we see this initiative more as an exploration test.*	BDA implementation was fully supported by top management. *As our operations are closely tied to costs and customer satisfaction, our executive level firmly believes we need good information from each of the production phases as to better estimate production times and costs, capacity utilization, prevent potential downtimes, reduce waste and secure appropriate quality.*
Financial resources	A specific budget was not allotted and the firm had limited financial resources. *We had reserved the funds for this investment, yet, these were limited as the parent company was restricting new IT investment funding.*	A minor budget within IT budget was assigned for exploring new technological solutions, yet, as there were many requests from throughout the firm the part allocated to BDA was rather small. *We included this technology investment in our regular yearly plan, but had to limit its amounts to 50.000 € as other competing requests for IT investments in other areas of the firm were heavily influencing the amount.*	The budget allocated was included in the yearly budget and was large enough to support the initiative. *The budget to fully introduce BDA was carefully planned for and secured in yearly financial planning. We managed to keep the project within the budget.*
Engaging employees	Employees (managers, specialists etc.) were brought to the project from its beginnings and were actively involved throughout the implementation.	BDA were implemented and employees were informed about the upgrade of the system. Only a short introductory seminar with handed out minutes was delivered, leaving many employees not really "buying-in".	During the implementation project regular meetings were organized where employees (managers, specialists etc.) were informed about the new capabilities as well as actively participated in the adjustments that needed to be carried out to fine-tune the operations.

Source: Interview transcripts.

5. Discussion

Our research considered how the introduction and utilization of BDA has transformed operations in the three case firms, our study found that utilization of BDA led to improvements in the performance of the firms' manufacturing operations.

The three case firms studied, utilized BDA to support a wide range of performance aspects in relation to their planning (e.g. schedule and cost variance, capacity utilization), manufacturing process (e.g. process downtime, machine efficiency, waste reduction), and quality assurance (e.g. defective units, rejected units). Across the three cases, the utilization of BDA was found to provide additional performance insights into various manufacturing phases and, had therefore, improved their performance indicators across these areas. Specifically, respondents emphasized four improvements the utilization of BDA had brought to their operations management. First, the utilization of BDA improved the prediction of potentially unfavorable events. BDA-enabled information did provide more comprehensive and accurate insights and confirmed findings from other studies (Waller and Fawcett, 2013, Babiceanu and Seker, 2015). Second, equipment availability for the manufacturing process had also improved as a result of exploiting BDA, consistent with (Munirathinam and Ramadoss, 2014). The benefit of BDA use in reducing manufacturing waste, aided the move towards lean manufacturing (Lee et al., 2013). Lastly, the utilization of BDA improved insights into identification of faulty products, further preventing returns and rework (LaValle et al., 2011).

Drawing on critics, who claim that firms only enjoy differential performance when IT is combined with capabilities that drive comparative advantage (Mithas et al, 2011) and is endorsed by other organizational factors (Oh & Pinsonneault, 2007; McLaren et al, 2011), we delved deeper within our cases to gain richer explanations of factors that may have influenced differential performance from BDA implementation in our sample. Our investigation raised some interesting insights. The three case firms differed in their BDA capability (Table 6), but also in organizational design/readiness factors (Table 7). Before BDA adoption, in all three firms, the decision-making was fixed, limited and heavily linked to organizational management structures and capabilities. However, after the adoption of BDA decision making became more flexible, dynamic and provided a level of agility that enabled all three firms to enhance their high value operations performance, to varying degrees. Consequently, our findings indicate that BDA capability along with organizational readiness and design facilitated better utilization of BDA in manufacturing. However, the degree to which there was full adoption and implementation of BDA in this respect was linked to both capabilities and organizational factors.

Figure 2. Enhanced High Value BDA Impact

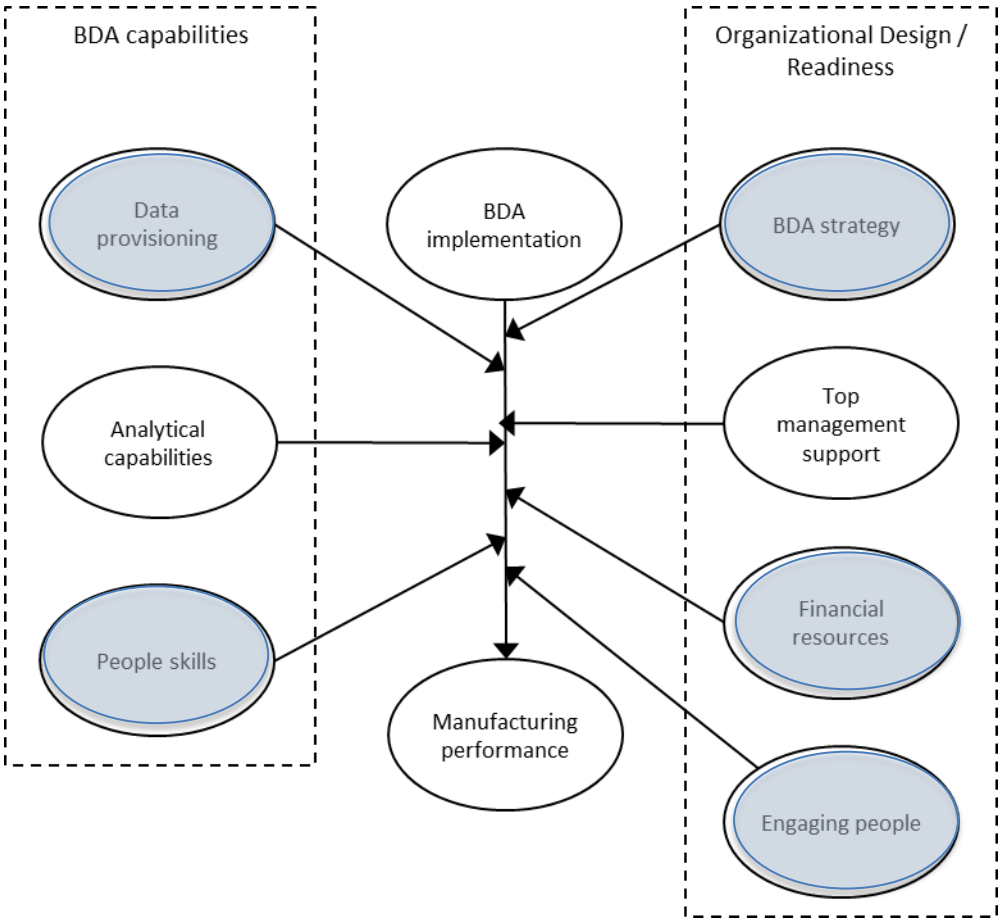

Figure 2 highlights the areas in our framework where there were significant differences between heavy, moderate and experimental users. While all the cases had availability of data, integration of data was a limiting factor for advanced BDA capabilities. All three cases had access to a variety of analytical capabilities functionality within the software ranging from the analysis to advanced simulation and optimization. With people skills, the moderate and heavy users had access to both internal and external expertise to ensure complete understanding of the types of problems and solutions emerging from the BDA, which was limited in the experimental user firm. From the organizational design/readiness perspective, all the case organizations had some kind of management support to varying degrees ranging from full to partial and this was also associated with BDA strategy and financial resources. Where there was no coherent BDA strategy and partial management support, the allocated financial resources also seemed to be ad-hoc and integrated within a broader general "IT budget". Engaging people was also found to be well-structured and planned long term in the moderate and heavy user firms, compared to the experimental user firm where the employees were only informed after BDA implementation with minimal information which limited buy-in.

Our results also highlight important high value managerial implications. Essentially, we recommend increased utilization of BDA in manufacturing operations, as this can facilitate cost reductions, improve planning, empower employees and improve decision making, foster better prediction of events and enhance customer satisfaction. As more and more big data

technologies are becoming readily available and, thus, not rare or hard to imitate, investing in these technologies per se is unlikely to yield differential performance returns against competitors. Instead, the performance impact is conditional upon the firm's capability of utilizing BDA to improve key performance areas of their operations. We, therefore, recommend that firms also pay attention to their BDA management capability and the organizational factors outlined in our findings, as these will facilitate better utilization of BDA in operations and will boost process benefits and high value performance returns. In particular, developing a BDA strategy for the organization and implementing a plan to train, inform and involve employees in the implementation of BDA. Lastly, in general, firms tend to engage in exploitation at the expense of exploration. Because the returns from exploiting existing resources are generally more certain than those from exploration, the former drives out the latter. Thus, the very possession of valuable resources paradoxically leads big data-rich organizations to focus an increasing amount of attention upon applying and improving them, at the expense of exploring and developing the new resources which are often required for strategic change.

6. Limitations and Further Research

Our results should be interpreted with caution, as it is not possible to completely rule out alternative explanations. An alternative explanation for the performance differences across the three case firms could be differences in firm size. One could suggest that Firm C (a heavy BDA user) had a larger system scope for implementation, and hence that size drove the enhanced use of BDA. Yet, on the flipside, we could also argue that the larger system size could have made it more challenging to implement BDA and leverage the operational benefits of systems integration. In either case, firm size did not emerge as an alternative explanation through our qualitative findings. One could also claim that firm age, the industry sector and location of the firms could have influenced our results. We, therefore, recommend that future studies control for firm size, age, and industry sector to account for performance differences attributable to organizational resources, inter-industry or country differences (Hendricks & Singhal, 2001).

Our case study design also limits our ability to generalize results to a wider population of firms. Hence, we recommend that researchers replicate and extend this study to wider contexts. For instance, we should underline that the change associated with implementation and utilization of BDA can be a costly and risky. In our study, all three firms were, in general, good performers across various indicators. Further research should study how BDA utilization influences manufacturing operations in lower-performing firms. Furthermore, studying failure cases will add valuable insights. For example, investments in process and IT were shown they can lead, ironically, to unintended technology traps over time (Grover & Malhotra, 1999), resulting in not only in process agility (Goodhue et al. 2009) but also rigidity (Galliers, 2007).

In addition, a longitudinal design would be desirable to further examine the causal dynamics of the relationships outlined in our conceptual framework. Moreover, further research should

delve deeper on the mechanisms that foster BDA capability building. Future research should extend our work and examine how other elements, such as firm structure and people, act together with BDA capabilities in enabling differential operations performance.

As the global environments in which businesses operate become more complex organizations must increasingly find innovative ways to differentiate themselves from competitors and respond to rapidly changing market needs. This is achieved through more collaboration, increased digitization, adaptiveness and agility. One of the major trends for many organizations to become more agile is to utilize the resources and capabilities of BDA to achieve these objectives. Having efficient and effective decision making processes with the right data that is transformed to be meaningful information with data-driven discoveries (e.g. analytics) are becoming mainstream processes for companies to run smarter, more agile and efficient businesses (Demirkan and Delen, 2013).

7. Conclusion

The full influence of BDA on manufacturing improvements are under explored and will not be fully exploited without a deeper understanding of mechanisms underlying their utilization in operations. Our research presents empirical evidence that demonstrates the impact of BDA in three manufacturing firms that have implemented and used BDA to varying degrees. In all three cases, the study has provided insights into how the utilization of BDA has improved operations and highlighted its link with enhanced business performance. By applying the conceptual framework developed in our research, which incorporates both the factors related to BDA capabilities and also organizational readiness and design, we have identified how organizations may improve BDA implementation, for instance with focused engagement and applied strategic thinking. Our research will inspire future attempts to elaborate understanding of the complexities apparent in BDA utilization towards the commendable objectives of a 'Better World' through productive economic societal changes.

References

AGARWAL, R. & DHAR, V. (2014) Editorial—"Big Data, Data Science, and Analytics: The Opportunity and Challenge for IS Research". *Information Systems Research,* Vol 25**,** 443-448.

AUSCHITZKY, E., HAMMER, M. & RAJAGOPAUL, A (2014). "How big data can improve manufacturing". McKinsey&Company.

BABICEANU, R. & SEKER, R. (2015) "Manufacturing Operations, Internet of Things, and Big Data: Towards Predictive Manufacturing Systems". *In:* BORANGIU, T., THOMAS, A. & TRENTESAUX, D. (eds.) *Service Orientation in Holonic and Multi-agent Manufacturing.* Springer International Publishing.

BENBASAT, I., GOLDSTEIN, D. K. & MEAD, M (1987). "The Case Research Strategy in Studies of Information Systems". *MIS Quarterly,* Vol 11**,** 369-386.

BHATTACHARYA, P. J., SEDDON, P. B. & SCHEEPERS, R. (2010) "Enabling Strategic Transformations with Enterprise Systems: Beyond Operational Efficiency". *In:* LACITY, M., MARCH, S. & NIEDERMAN, F., eds. 31st International Conference on Information Systems, 2010 St. Louis, MO, USA. Association for Information Systems, 1-12.

BI, R., DAVIDSON, R., KAM, B. & SMYRNIOS, K. (2013) "Developing Organizational Agility through IT and Supply Chain Capability". *Journal of Global Information Management (JGIM),* Vol 21**,** 38-55.

CASSELL, C. & SYMON, G. (1994) "*Qualitative Methods in Organizational Research: A Practical Guide",* London, UK, Sage Publications.

CHAKRAVARTY, A., GREWAL, R. & SAMBAMURTHY, V. (2013) "Information Technology Competencies, Organizational Agility, and Firm Performance: Enabling and Facilitating Roles". *Information Systems Research,* Vol 24**,** 976-997.

CHEN, H., CHIANG, R. H. L. & STOREY, V. C. (2012) "Business Intelligence and Analytics: From Big Data to Big Impact". *MIS Quarterly,* Vol 36**,** 1165-1188.

CHEN, X. & SIAU, K. (2011) "Impact of Business Intelligence and IT Infrastructure flexibility on Competitive Performance: An Organizational Agility Perspective". *In:* BEATH, C., MYERS, M. D. & WEI, K. K. (eds.) *32nd Infernational Conference on Information Systems.* Shanghai, China: Association for Information Systems.

CHEN, Y., WANG, Y., NEVO, S., JIN, J., WANG, L. & CHOW, W. S. (2014) "IT capability and organizational performance: the roles of business process agility and environmental factors". *European Journal of Information Systems,* Vol 23**,** 326-342.

DAVENPORT, T. H., BARTH, P. & BEAN, R. (2012) "How Big Data Is Different". *MIT Sloan Management Review,* Vol 54**,** 43-46.

DAVERN, M. J. & KAUFFMAN, R. J. (2000) "Discovering Potential and Realizing Value from Information Technology Investments". *Journal of Management Information Systems,* Vol 16**,** 121-143.

DEMIRKAN, H., & DELEN, D. (2013) "Leveraging the capabilities of service-oriented decision support systems: Putting analytics and big data in cloud". *Decision Support Systems*, Vol *55*(1), 412-421.

DUTTA, D. & BOSE, I. (2015) "Managing a Big Data project: The case of Ramco Cements Limited". *International Journal of Production Economics,* In Press.

EISENHARDT, K. M. (1989) "Building Theories from Case Study Research". *The Academy of Management Review,* Vol 14**,** 532-550.

FIRESTONE, W. A. & HERRIOTT, R. E. (1983) "The Formalization of Qualitative Research: An Adaptation of "Soft" Science to the Policy World". *Evaluation Review,* Vol 7**,** 437-466.

FOSSO WAMBA, S., AKTER, S., EDWARDS, A., CHOPIN, G. & GNANZOU, D. (2015) "How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study", *International Journal of Production Economics,* Forthcoming.

GANDOMI, A. & HAIDER, M. (2015) "Beyond the hype: Big data concepts, methods, and analytics". *International Journal of Information Management,* Vol 35**,** 137-144.

KIRON, D. (2013) "Organizational Alignment is Key to Big Data Success". *MIT Sloan Management Review,* Vol 54**,** 1

KIRON, D., PRENTICE, P. K. & FERGUSON, R. B. (2012) "Innovating With Analytics". *MIT Sloan Management Review,* Vol 54**,** 47-51.

KIRON, D., PRENTICE, P. K. & FERGUSON, R. B. (2014) "Raising the Bar With Analytics". *MIT Sloan Management Review,* Vol 55**,** 29-33.

KRETZER, M., MAEDCHE, A. & GASS, O. (2014) "Barriers to BI&A Generativity: Which Factors impede Stable BI&A Platforms from Enabling Organizational Agility?" 20th Americas Conference on Information Systems, 2014 Savannah, GA, USA. Association for Information Systems.

LAVALLE, S., LESSER, E., SHOCKLEY, R., HOPKINS, M. S. & KRUSCHWITZ, N. (2011) "Big Data, Analytics and the Path From Insights to Value". *MIT Sloan Management Review,* Vol 52**,** 21-32.

LEE, J., LAPIRA, E., BAGHERI, B. & KAO, H.-A. (2013) "Recent advances and trends in predictive manufacturing systems in big data environment". *Manufacturing Letters,* Vol 1**,** 38-41.

MCAFEE, A. & BRYNJOLFSSON, E. (2012) "Big data: the management revolution". Harvard *Business Review***,** 3-9.

MELVILLE, N., KRAEMER, K. & GURBAXANI, V. (2004) "Information Technology and Organizational Performance: An Integrative Model of IT Business Value". *MIS Quarterly,* Vol 28**,** 283-322.

MILES, M. B., HUBERMAN, A. M. & SALDANA, J. (2014) "*Qualitative Data Analysis: A Methods Sourcebook",* Thousand Oaks, CA.

MITHAS, S., RAMASUBBU, N. & SAMBAMURTHY, V. (2011) "How Information Management Capability Influences Firm Performance". *MIS Quarterly,* Vol 35**,** 237-256.

MUNIRATHINAM, S. & RAMADOSS, B. (2014) "Big data predictive analtyics for proactive semiconductor equipment maintenance". IEEE International Conference on Big Data, 2014. 893-902.

POPOVIČ, A., HACKNEY, R., COELHO, P. S. & JAKLIČ, J. (2012) "Towards business intelligence systems success: Effects of maturity and culture on analytical decision making". *Decision Support Systems,* Vol 54**,** 729-739.

POPOVIČ, A., HACKNEY, R., COELHO, P. S. & JAKLIČ, J. (2014) "How information-sharing values influence the use of information systems: An investigation in the business intelligence systems context". *The Journal of Strategic Information Systems,* Vol 23**,** 270-283.

SACKETT, P.J., and Bryan, M.G. (1998) "Framework for the development of a product data management strategy", International Journal of Operations & Production Management Vol 18,2, 168-179

TALLON, P. P. & PINSONNEAULT, A. (2011) "Competing perspectives on the link between strategic information technology alignment and organizational agility: insights from a mediation model". *MIS Quarterly,* Vol 35**,** 463-484.

van OOSTERHOUT M., WAARTS, E., & van HILLEGERSBERG, J. (2006) "Change factors requiring agility and implications for IT". *European Journal of Information Systems*, Vol *15*(2), 132-145.

WALLER, M. A. & FAWCETT, S. E. (2013) "Data Science, Predictive Analytics, and Big Data: A Revolution That Will Transform Supply Chain Design and Management". *Journal of Business Logistics,* Vol 34**,** 77-84.

WIXOM, B. H. & TODD, P. A. (2005) "A Theoretical Integration of User Satisfaction and Technology Acceptance". *Information Systems Research,* Vol 16**,** 85-102.

YIN, R. K. (2012) "*Applications of Case Study Research",* Thousand Oaks, CA, SAGE Publications, Inc

YIN, R. K. (2014) "*Case Study Research: Design and Methods",* Thousand Oaks, CA, SAGE Publications, Inc.

ZELBST, P. J., GREEN JR., K. W., SOWER, V. E. & ABSHIRE, R. D. (2011) "Radio Frequency Identification Techonology Utilization and Organizational Agility". *Journal of Computer Information Systems,* Vol 52**,** 24-33.