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Abstract: Industry 4.0 has been a hot topic in several markets and its innovations are proving to be paramount for the strategic position of the companies in the market. The objective of this study is to explore the changes carried out by the 4th industrial revolution in the supply chain area, mainly in the procurement department. To develop this issue, a qualitative and exploratory research based on bibliographical references was investigated and a case-study analysis was applied based on e-auction tools in order to collect data and identify improvements for the next level of Procurement 4.0 strategies. It shows the possibility to provide horizontal system integration to the supply chain, collecting price data to perform big data and analytics to achieve better performance on bidding results and autonomously perform challenging targets on real-time.

Keywords: Industry 4.0; Supply Chain 4.0; Procurement 4.0; purchasing chessboard.

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1 Introduction

Since the beginning of industrialisation, technology leaps have led to paradigm shifts that are now known as industrial revolutions. As shown of Table 1, the so-called 1st industrial revolution occurred between the 18th and 19th centuries in the mechanical field, from the use of steam machines. The 2nd industrial revolution in the 20th century counted on the intensive use of electric energy and was characterised by the development of mass production in industries and production lines. In the second half of the same century, with the generalised digitalisation, there was the so-called 3rd industrial revolution, counting on the use of computers in the industries that enabled greater automation of machines and processes in the industry. Nowadays, advanced digitisation inside the factories, the combination of internet technologies and future-oriented technologies in the field of intelligent objects (machines and products) seems to result in a new fundamental paradigm shift in industrial production, and the term Industry 4.0 was established supposing a 4th industrial revolution (Brettel et al., 2014).

Technology has changed the way we conceive business. The emergence of the new digital industrial technology, known as Industry 4.0, directly affects all organisational areas of the companies, since one of the main objectives of the fourth revolution is to interconnect the areas that make up the production process through digital networks. With advances in areas of technology, information technology, and robotics, companies seek greater competitiveness in the global scenario (Del Val Román, 2016).

Table 1 Characteristics of industrial revolutions

Industrial revolution	*Time period*	*Characteristics*
First	1760–1840	Mechanisation, caused by the construction of railways and the invention of the stream engine
Second	Started at the end of the 19th century	Mass production, the emergence of electricity an the assembly line
Third	Started at the 1960s	Digital revolution, driven by the computing development and the internet, when it becomes common to use electronics and IT in production processes
Fourth	Currently in progress	Fusion of technologies and integration between the physical, digital and biological domains

Source: Sigahi and Andrade (2017), Weiss et al. (2016) and Schwab (2016)

Among the organisational area that have most changed with the aspects of Industry 4.0 is the supply chain. There are so many innovations that we are currently talking about Supply Chain 4.0, a term that refers to digital and electronic solutions in areas such as

procurement, logistics and production planning. Still, in the logic of Supply Chain 4.0, terms such as Sourcing 4.0 and Procurement 4.0 were adapted from e-sourcing and e-procurement, as a result of the digitisation of procurement processes and supply chain management that today occurs in companies more aligned with the 4th industrial revolution (Rojas and Rauch, 2019)

In Brazil, about 64.9% of the electricity generated in 2019 came from hydroelectric plants, due to a poorly diversified energy matrix (EPE, 2021). This situation increases the importance of solutions for power systems, such as electrical substations, transmission lines, high-voltage direct current systems and power transformers. These scopes are of the utmost importance for national energy transmission, distribution, and consumption (Jussani et al., 2017).

In the companies which work with these kinds of solutions, the supply chain and procurement areas need to deal with the acquisition from commodities to engineered solutions projects. From small services to construction and assembly of large substations and electrical systems. Thus, the need to have a robust supply structure to guarantee a competitive company, make tools, solutions and strategies related to Procurement 4.0 extremely important for their scenario (Tomasson and Soder, 2020).

1.1 Research justification

The purpose of this study is to explore the innovation brought by the Industry 4.0 as well as its application in procurement, identifying their impact and opportunities (Kirihata, 2018). To accomplish this, a literature review on topics such as Industry 4.0 itself, e-procurement and Procurement 4.0 was performed and a case-study was investigated based on the application of e-procurement tools in a global company from the power systems business. The research deals with a real company which has been implementing Procurement 4.0 processes and has ongoing actions related to this. Therefore, the research is limited to the actions that were implemented partially in the company until the date of this publication.

The study first clarify the main concepts related to Industry 4.0, correlate it to Procurement 4.0, and try to demonstrate the benefits to companies by adopting e-procurement solutions and tools, through a case-study which applied e-auction contained in the methodology of purchasing chessboard in a multinational company of the power systems sector. Besides that, it is intended to present how the purchasing strategy has been developed and applied throughout the company. Finally, some recommendations are provided for the company in order to further develop its current process on e-auction using big data and analytics to reach the state-of-the-art on Procurement 4.0 (Zeisel, 2020).

2 Literature review

The literature review contributes to the foundation for structuring the research. The subject matters like Industry 4.0, e-procurement, and Procurement 4.0 are presented as follow.

2.1 Industry 4.0

The 4th industrial revolution has been changing the way goods are produced, managed and delivered to the market recently. The term Industry 4.0 emerged in Germany during the Hannover Fair in 2011 from a government project aimed at developing industrial technologies and stimulating the competitiveness of intelligent factories (De Souza and Gasparetto, 2018). According to Kagermann (2013), the development of Industry 4.0 will provide greater products and services customisation so that companies continue to increase profits and customer satisfaction. It will be possible due to greater flexibility in production, so that changes in products will be more easily implemented and failures will be identified with greater assertiveness. Thus, according to the author, "there will be improvements in production processes, in product engineering, in the supply chain, and in life cycle management."

Table 2 Technological trends in Industry 4.0

#	*Technology*	*Definition and references*
1	Big data and data analytics	Large datasets that can be analysed computationally to reveal inconsistent process or availability and visualise results. Gomes and Braga (2017) argue that the large amount of information that generates the big data is based on 4V's: volume (large amount of data and information), variety (data sources are diverse such as emails, social networks, and sensors), velocity (information generated in real-time) and veracity (consider a certain level of uncertainty, which should always be the smallest possible).
2	Autonomous robots	Robots that can obtain information about the environment, adapt, and make decisions without the need for human intervention. Autonomous robots drive innovation and the value of the supply chain primarily by reducing direct and indirect operating costs and increasing revenue potential (McKinsey & Company, 2016).
3	Simulation	Integration of physical and virtual entities to model, design, simulate, monitor, and protect physical processes in a virtual environment. Most of the time, simulation software is used to develop simulation models to evaluate the design of a manufacturing system (BCG, 2019).
4	Systems integration (horizontal and vertical)	A more cohesive collaboration between companies, allowing horizontal and vertical data integration networks, providing truly automated value chains. This integration makes possible more strategic management of the network of suppliers from tools that aid decision-making and the operationalisation of transactional processes (BCG, 2019).
5	Internet of things (IoT)	Allows the integration of physical and virtual objects through the internet and wireless technology, facilitating the collection and exchange of data. Therefore, it becomes possible to communicate between objects without the human intermediation, as well as real-time responses, since analysis and decision-making no longer need to be centralised (Coelho, 2016; Borlido, 2017).
6	Cybersecurity	Protection of computer systems against theft or damage to hardware, software, or information and for the interruption of services provided. In the context of Industry 4.0, cybersecurity plays an important role in preventing leakage of data. In fact, critical industrial equipment is now vulnerable to multiple cyber-attacks due to its connectivity (BCG, 2019).

Source: Adapted from BCG (2019)

Table 2 Technological trends in Industry 4.0 (continued)

#	*Technology*	*Definition and references*
7	Cloud computing	Remote server software and hardware services used to store, manage, process, and view data, rather than a local server. Cloud-based platforms are designed to help companies improve their service levels by coordinating partners in the supply chain network (retailers, vendors, and distributors). These platforms can collect sales data via the internet, carry out basic analyses and, consequently, execute more accurate statistical forecasting of demand for all participants in the supply chain (Schramm et al., 2011). Cloud computing is also useful for inventory, storage, and transportation management as it provides logistics tracking operations for multiple supply chain partners. Processes such as replenishment planning, order processing, fleet management, transport route planning, and global trade compliance can migrate to the cloud (Schramm et al., 2011).
8	Additive manufacturing	Digital design data is used to create a three-dimensional object in which layers of material are formed under computer control. Today it is used to produce physical prototypes and unique pieces. Due to the need for mass customisation in Industry 4.0, non-traditional manufacturing methods are required to be developed. Thus, additive manufacturing can become a key technology for manufacturing custom products because of its ability to create sophisticated objects with advanced attributes of new materials and shapes (Dilberoglu et al., 2017).
9	Augmented reality (AR)	Superimposing computer-generated images combined with object recognition for a real-world user's vision, giving an interactive hybrid view. Since its early research, AR has been recognised as interesting support in the industry for machine maintenance, assembly, and repair applications. One of the main advantages of the use is that the operator can access the information needed to carry out the activities directly in the work area, without the need to consult the traditional printed manual (BCG, 2019).

Source: Adapted from BCG (2019)

According to De Souza and Gasparetto (2018), one of the main factors that led to the rise of the 4th industrial revolution was the growth in data volume from computing and the democratisation of connectivity. This, coupled with the progress of analytical capabilities, would be one of the main fronts of Industry 4.0, which is the big data and data analytics.

In order to understand better the consequences and transformations of Industry 4.0, it is important to identify its main aspects. According to the BCG (2019), nine technological trends form the pillars of this revolution, presented in Table 2.

2.2 E-procurement

The term e-procurement or electronic procurement refers to operations of buying and selling products and services using the internet. In the organisational context, it is very related to business-to-business (B2B), with the support of software and electronic methods for conducting business operations between companies in virtual environments.

The main gain in the use of e-procurement was the possibility of the resources focusing on strategies and tactics of purchase and the management of the supply chain, being able to spend less time with operational activities that add little or none to the process (Giunipero and Sawchuk, 2000). Thus, one of the main advantages of

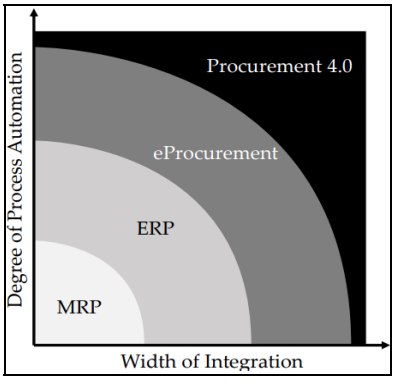
e-procurement is the gain of agility in the processes since automation tools of the purchasing process promote faster and targeted quotations to companies able to meet a certain need through request for quotations (RFQ's). In addition, it provides greater clarity and objectivity to procurement professionals by comparing budgets more efficiently and enhancing business aspects more relevant to strategic buyer decision making (Chen et al., 2019). As second of the most important aspects of using e-procurement software, there is also cost reduction provided by electronic auctions and other applications that increase competition between suppliers and improve end customer service, given the better management of the supply chain that the company will obtain (Garay-Rondero et al., 2020). The sum of these advantages promotes a competitive advantage to the company that adopts e-procurement, making it more competitive and efficient in the face of competition, as pointed out in the Grupo Imam's (2018) magazine. The reasons why e-procurement has become so prevalent according to the previous researchers are:

- Cost reduction: While saving money is just one aspect of good shopping practice, it is one of the key drivers of e-procurement. The ability to access a wider range of vendors and the different bidding approaches that systems facilitate can deliver incredibly successful buyer results (Cherian et al., 2020; Mufleh, 2020).
- Reduced sourcing lead-time: E-procurement systems also streamline procurement processes, reducing the total time for a bidding process and reducing the number of hours that purchasing managers spend on bids, freeing up valuable time for them to focus on strategic activity (Wibowo, 2019; Belisari et al., 2019).
- Strengthens supplier relationships: E-procurement can bring great improvements in transparency and openness between buyers and suppliers. The systems provide a portal through which suppliers can view all the bidding opportunities of a vendor, with deadlines, current status and final results all clearly presented. Interaction through the system ensures rapid communication and effective feedback so that suppliers are always aware of the current situation (Cardoso and Biazzin, 2020, Pawar et al., 2017).
- Compliance improvement and risk reduction: Systematic approach to e-procurement processes give companies control over their bidding processes and an audit trail for compliance purposes (Tutu et al., 2019; Al-Yahya and Panuwatwanich, 2018).

2.3 Procurement 4.0

As shown on Figure 1, IT application in business organisations has developed since the 1970s, where the demand for production materials was structured using a simple electronic system known as material requirements planning (MRP). The next step in the use of IT in procurement was characterised by a stronger integration among IT systems companies, also known as enterprise resource planning (ERP). Here the use of systems is intended to provide a common basis for all the major business functions in a company, ranging from sales over finance, production, to acquisitions (Wang et al., 2020).

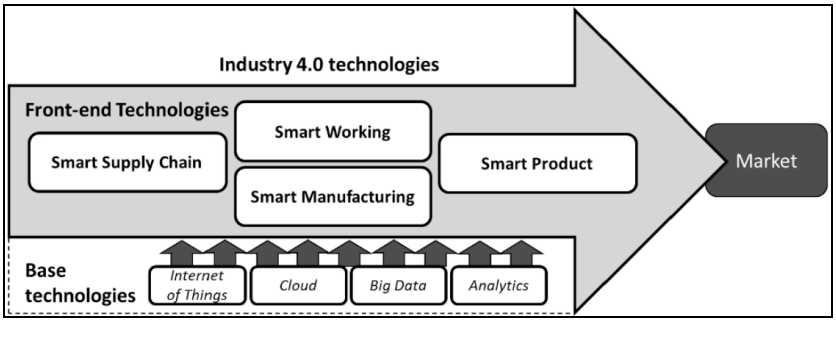
Figure 1 The evolution of procurement IT systems towards Procurement 4.0



Source: Glas and Kleemann (2016)

From a technological point of view, the systems are used to facilitate tasks that previously required a lot of work, such as connecting suppliers with the requesting company through electronic data interchange (EDI) systems. Many studies show that e-procurement, in general, has been widely adopted in organisations, with specific instruments such as search-to-pay operations (also known as P2P, is a process of obtaining raw materials necessary for the production of a service) (McCue and Roman, 2012). In addition to productivity gains in processes, e-procurement can be considered as one of the enabling pillars of Industry 4.0 considering the current context in which, once again, the value of the individualisation of orders and products is valued. As shown of Figure 2, with the term and cost gains generated by the processes' digitalisation, production can occur in a more flexible way and customer service in a more personalised way.

Figure 2 Theoretical framework of Industry 4.0 technologies



Source: Frank et al. (2019)

The productivity paradigm in terms of improved collaboration productivity in Industry 4.0 (Schuh et al., 2014) is used to identify differences between Industry 4.0 and the existing Procurement 4.0 approach. Electronic delivery transforms paperwork into electronic software systems and then shifts from heavy work tasks to IT workflow and support processes, smart working on Figure 2. Likewise, e-procurement also supports strategic tasks, such as the supplier relationship management process (Essig and Arnold,

2001), smart supply-chain on Figure 2. In addition, Industry 4.0's key collaboration productivity drivers are improvements in production and engineering. According to Schuh et al. (2014), Industry 4.0 enables radically short production development processes, enables new product service functions, and improves organisational supply chain configuration for product customisation, smart manufacturing and product on Figure 2. Taken to the extreme, e-procurement is focused on pure process efficiency, while Procurement 4.0 goals are extended to increase productivity and performance to meet highly customised demands (Schiele and Torn, 2020).

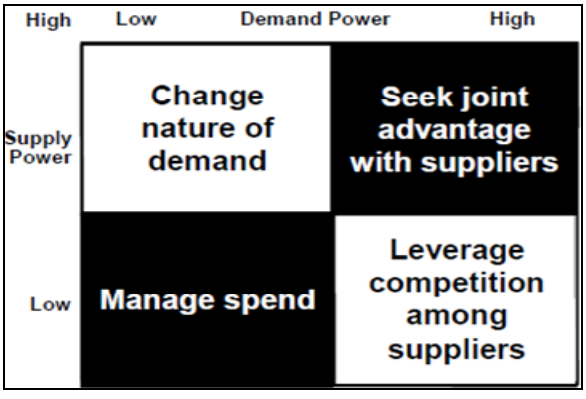
3 Methodology

For this research we have performed a case-study in a multinational company which operates on several technological markets, mainly providing solutions, services and products for industry and energy. Inserted in the energy market, the business unit where the study has been developed deals with power systems of generation, transmission and distribution. It is also important to delimitate that the research took place in Brazilian operation with data obtained between 2017 and 2020. The company's procurement team is always improving and updating the purchasing strategies, however for this research it has been considered the Kraljic matrix and the purchasing chessboard as strategies to understand and classify the appropriate acquisition methods for each equipment or category. This step has been previously performed by the procurement team, then the categories which have reverse auctions as a purchasing strategy were already defined. In the case-study there will be an explanation on three different types of reverse auction according to the company's understanding and the results obtained by their experience: Japanese, English and Dutch, which were executed in Emptoris, a well known tool on the procurement market. The frequency to execute each type of e-auction has always been defined by the buyer with the support of a sourcing specialist. It was analysed almost more than 50 sourcing events performed over three years, from which almost 40 were Japanese, Duch or English reverse auctions. Regarding Procurement 4.0, the company's study is increasingly betting on reverse e-auctions and RFx processes (RFI and RFP).

As mentioned in Menezes et al. (2007), reverse e-auctions should have simple and well-defined rules for suppliers, being able to achieve good results in terms of price reduction, agility, and transparency in B2B relations. The reverse auction is used as an acquisition strategy based on the methodology of purchasing chessboard (Schuh et al., 2009), based on four major purchasing strategies, which have the market supply power and the demand power as variables. Figure 3 is a brief explanation of the four purchasing chessboard strategies.

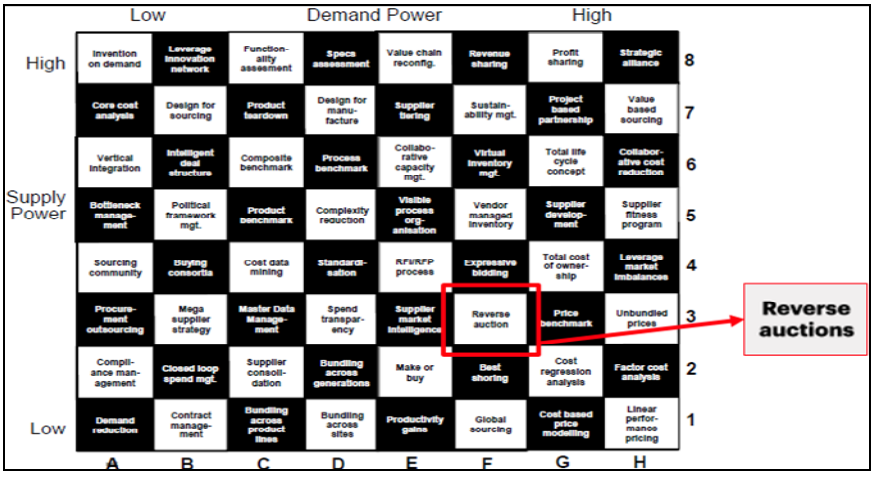
Change the nature of demand – one of the main cases in which the high strength of the selling company is observed is when the supplier can achieve a monopoly or oligopoly due to a strong (often technical) competitive advantage. Thus, the strategy of changing the nature of demand seeks to explore the limits of the need for a buyer to reclaim competition in the market. In other words, the purchasing company seeks to develop new technical alternatives (re-specification of components) for its necessity so that it can find a viable alternative in markets with greater competition.

Figure 3 Four purchasing chessboard strategies



Source: Schuh et al. (2009)

Figure 4 64 methods of purchasing chessboard (see online version for colours)



Source: Schuh et al. (2009)

Seek joint advantage with supplier – since in this scenario the power of the supplier and the buyer are high, the strategy is to look for joint advantages between both players, building partnerships of good cost and realising integrated and transparent operations. In this case, the intensity of the partnership and its form will take place will vary.

Manage spend – in the case where there are reduced powers of both supplier and buyer, good demand management is essential. According to the A.T. Kearney (Schuh et al., 2009), "managing spending requires detailed knowledge of who is buying what from which supplier." A good alternative to the low demand but cutting costs and adding value is through volume consolidation in order fulfilment, which slightly increases the buyer's power towards the supplier.

Leverage competition among suppliers – in this scenario, the power of demand is high and that of suppliers is lower. Aiming to increase the possibility of gains to the buyer, this strategy brings methods that stimulate competition between suppliers. For this purpose, it is used, for example, the dissemination of target prices, requests for proposal

review and the conduct of auctions to intensify competition and encourage price reduction (Steiner and Brandhoff, 2021).

Knowing the four strategies of purchasing chessboard, it is possible to select some negotiation methods according to demand and supply power. As shown in Figure 4, reverse auction is a method to stimulate competition among market players. Therefore, the company studies are based on the methodology of A.T. Kearney (Schuh et al., 2009) and promotes reverse auctions for purchasing categories of materials whose supplier strength is less relative to the strength of the company. Through reverse auctions, it is possible to provide horizontal system integration to the supply chain, collect price data to perform data analytics to achieve better performance on bidding results and autonomously perform challenging targets in real-time.

4 Case-study

Regarding this research case, the application of the reverse e-auctions methods occurred in a multinational company from the power systems business, which deals with energy transmission and distribution. The e-auctions took place between 2018 and 2019 and were led by the company's Brazilian supply chain team in order to purchase materials and solutions for projects that the company was working on. The company has adopted three types of reverse auctions: Japanese, English, and Dutch.

4.1 Reverse auctions events

According to Pawar et al. (2017), before the organisation reviews their processes in order to include reverse auction strategies, the company needs to identify the items or scopes commonly requested and analyse if they should use reverse auction or not. There are three main aspects a company needs to analyse: first, the category for purchasing must have preferentially a low complexity, belonging short agreements contracts with low switching costs and finally being inserted in a market with high rivalry among suppliers. The recommended way to achieve these responses is performing the Kraljic (1983) matrix analysis, for each category as part of the procurement strategy definition. In the studied company, the supply chain management team had performed these steps previously and has determined the categories that could be included as reverse auctions scopes.

For acquisition of categories in the leverage quadrant, the company has adopted three types of reverse auctions: Japanese, English, and Dutch. All the reverse auctions have been operated through Emptoris, one of the most prominent e-sourcing tools in the market as an electronic alternative to previously manual techniques. With Emptoris, it is possible to parameterise the reverse auctions and other e-sourcing methods such as requests for proposals (RFPs) and requests for informations (RFIs). The tool automatically sends invitations to the participants, schedules the electronic events to the established date and automatically starts them according to the parameterisation stipulated by the auctioneer, without necessarily being operating the tool live. In addition to these utilities, Emptoris provides a chat for the auction operator to communicate with suppliers, file attachment spaces and even a database of all participants already registered. Below there are some variables which may be customised by the auctioneer

before at the auction design step. It is important to highlight that the main intention is to manage these variables in order to increase competitiveness between the players.

Following are the variables which customisation are needed:

- visibility: rank and lead, bid, rank only, lead or not, full visibility, all prices
- decrement or minimum decrement value
- length
- extension
- auction initial price
- ceiling price
- clock time
- price increase (reverse Dutch only)
- price entering.

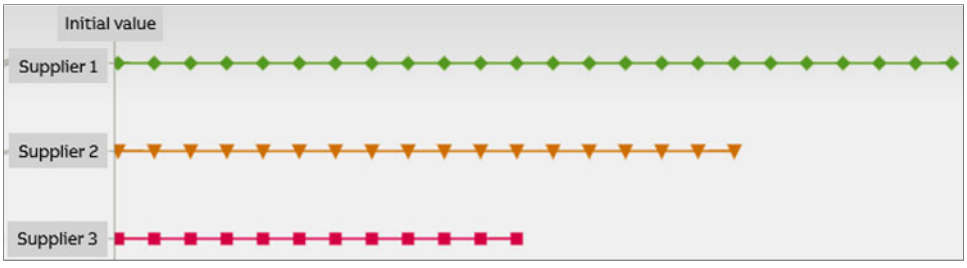
Among the three types of reverse auctions the company has adopted, the Japanese reverse auction is the most commonly used, mainly because of its greater range of scenarios in which it can be operated. As discussed by Noussair et al. (2004), the traditional Japanese auction starts with an initial value and the auctioneer inserts small increases in value each round, with participants having the option of accepting the non-value of each cycle. Since supply chain is dealing with an acquisition and the intention is to reduce the purchase value, the Japanese reverse auction is used. In this case, the auctioneer parameterises the initial value, which must be equal to or less than the maximum available budget, the decrease values that will be applied in the initial value in each round, insert the competitors and finally defines the event date and time. After setting these inputs, the tool is able to operate alone. Invitations are automatically sent to suppliers, and at the scheduled date and time the competitors will be able to bid without buyer's interference. The Japanese reverse auction starts at the previously parameterised value and decreases in values and time intervals also stipulated by the auctioneer in settings. At each round, suppliers can either accept or decline the value of the tie, and the last vendor who remains accepting the bids will be the winner. The great bonus of the Japanese reverse auction is that we can choose if the participants will or will not have access to information on the number of users that remain active in the auction; so it is possible for a supplier to continue reducing its price even after its competitors' exit, thus ensuring to achieve the best possible purchase value.

In Figure 5, there is a typical example of a Japanese reverse auction held in the company with three suppliers. The initial value, as stated above, will be equal to or less than the available budget for the purchase of the material. In this case, it is possible to notice that even after suppliers 2 and 3 have withdrawn, supplier 1 continues to send bids on its own value, making it possible to achieve the best possible value. It is important to note that, due to integrity issues, suppliers are aware that this might occur, since this and other points regarding the electronic competition are always aligned with the participants in advance.

The traditional English auction is the most popular auction mode (Salant, 2014). In this one, the competitors can see the values offered by the other participants and seek to

override the bids until the largest is not surpassed by anyone else. In the case of an English reverse auction, the essence is the same, but aiming at reducing prices. Thus, competitors begin the dispute with the value of their proposals previously sent to the buyer through an RFQ. In Emptoris, once again the purchaser can set the visualisation parameters for each event. In order to increase competitiveness, it is possible to let the owner of winning value that he is in the first position, and the other participants receive the input that they are not in the first place. Thus, the event unfolds with each supplier offering price reductions in order to reach the first placement and considering that the value and time between the bids depend on the suppliers (they are not parameterised in advance), and then the decision-making time can be longer. By providing a higher competitive climate, the company usually opts to use the reverse English auction when it is known that there is already strong competition among the suppliers of the product category in question.

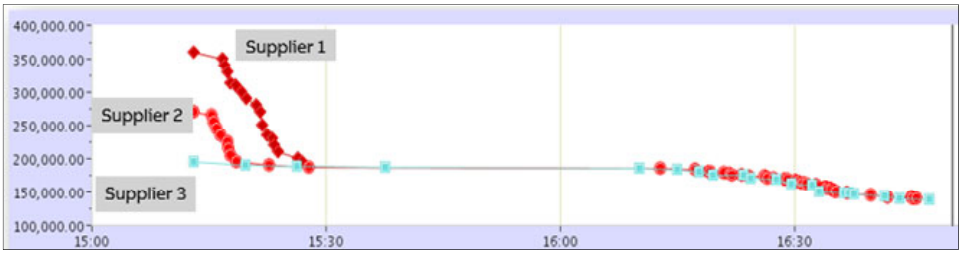
Figure 5 Japanese reverse auction (see online version for colours)



Source: Elaborated by the authors

Figure 6 shows this competition process. As mentioned, the initial value is different for each supplier because it corresponds to the value of the previous proposal. It is possible to note that supplier 3 starts first and maintains its price until one of the other participants reaches it. From that moment, the dispute for the first place begins. It is also interesting to note that from the time 16:00 onwards there is fierce competition for the prize, which in the end is guaranteed by supplier 3 with the best value.

Figure 6 English reverse auction (see online version for colours)

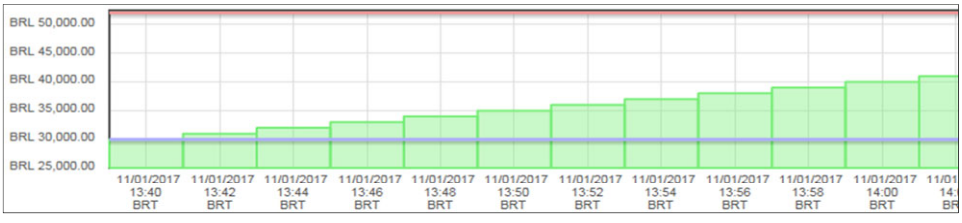


Source: Elaborated by the authors

Besides the categories presented, the company also adopts the Dutch reverse auction (Daudt and Willcox, 2018). Similar to the Japanese reverse auction, the auctioneer previously inserts some parameters in the tool such as round time (usually between one or two minutes), fixed bid values, which will be valid for all participants, and inserts the

purchase budget and finally the initial value of the auction. As a strategy, the initial value tends to be very low in relation to the market value of the acquisition, since each round will suffer small increases. In Figure 7, it is possible to note that the start value was 30,000 BRL and the inserted limit (budget, reserved value) was 50,000 BRL. After some increases, one participant won the supply by giving the bid before its competitors in the amount around 40,000 BRL.

Figure 7 Dutch reverse auction (see online version for colours)



Source: Elaborated by the authors

Finally, it is important to point out that there are strategies defined by each buyer about the use of reverse auction types in the Emptoris tool. Such strategies were built not only from a bibliographic study but mainly from the know-how acquired by the purchasing professionals during the negotiations in this specific market and from the exchange of experiences among the agents of the supply chain. These e-sourcing tools promote reliability and transparency in procurement processes and are increasingly being accepted by both internal project teams and the company's suppliers and partners.

5 Research results

For this research, it was made available by the company the auction data and results from 2017 to 2020 performed by the Brazilian procurement team from one of the company's business unit. Throughout three years there have been performed almost 40 reverse auctions considering its three types – Japanese, Dutch and English. There were considered two main baselines for the savings calculation: best initial offer and project budget.

- Best initial offer is the best offer obtained in a RFQ round previously from the reverse auction event. It is important because it shows the market level of price for the scope before the negotiations.
- Project budget is the value available for the scope purchasing. It is a predetermined value which comes from the project costs and is often used as a target price for the procurement processes.

In this article, it was considered the best initial offer as the baseline for the results. It is fairer since the offer comes from the supplier, then it was compared the real cost reduction during the negotiation and auction process. Besides that, there was not found a trustful consolidated database that could compare the project budget and the auction results. It could be improved by the implementation of a closed loop system, which is one of the differences among e-procurement and Procurement 4.0 processes.

Considering the performed reverse auctions between 2017 and 2020 the average cost reductions with the best initial offer as a baseline were these below. It is important to note that Japanese reverse auction type was more than 70% of the carried-out events, so it has a more faithful sampling.

- reduction of 13.2% for Dutch reverse auctions
- reduction of 19.2% for English reverse auctions
- reduction of 14.2% for Japanese reverse auctions.

6 Conclusions and recommendations

This article aimed to study the innovation of Procurement 4.0, a purpose that was fulfilled not only from a bibliographic study but mainly demonstrated through a case-study application in a multinational company about the impact of the adoption of some of these digital technologies.

Thus, the academic contribution of this research is that several studies about application of Industry 4.0 technologies are limited in the production field. This article presented the application of Industry 4.0 technology in the field of procurement which contributes to broaden the field of application of these technologies.

In addition, there is an industry contribution with a case-study applied in a company of power systems industry, it was possible to show the results using e-procurement tools through reverse auctions, providing horizontal system integration to the supply chain, collecting price data to perform data analytics to achieve better performance on bidding results and autonomously perform challenging targets on real-time.

As part of Procurement 4.0 digital tools, reverse e-auctions were executed in the acquisition processes for supply chain integration, and a cost reduction of around 35% of the best initial offer was achieved, a result that proves the efficiency that aligns good e-sourcing tools to the know-how of the purchasing professional.

The e-auctions offer great promise as mechanisms for the optimal allocation of resources in complex distributed systems with interested agents. The value of auctions will depend on the ability to maintain its desirable properties, e.g., economic efficiency, strength, and simplicity, as methods are introduced to enable tractable computing. After computational problems are successfully solved, auctions can provide simple, stable, and robust solutions to many important distributed problems.

In summary, the main contributions of reverse auction to e-commerce are:

- An iterative combinatorial auction that calculates competitive equilibrium minimum prices in the combinatorial allocation problem, with myopic best-response agent strategies.
- An iterative combinatorial auction that calculates efficient allocation and payouts can be priced competitively (nonlinear and perhaps non-anonymous) with short-sighted best responsive agents' strategies.

A reverse auction provides buyers with the most competitively priced solution for their needs, putting suppliers against each other to offer the lowest price offer. It also simplifies the purchasing process and reduces the need to send a different request for proposal to each potential supplier. It also saves time in the purchasing process.

6.1 Limitations of the research

The main problem with this type of auction is that it is based solely on price. Unless the request for proposal is very clearly constructed and specific, the buyer may find that the lowest bid is not the one with the highest quality or does not offer all the features expected. The costs of performing due diligence on the winning bid and managing the project can outweigh the savings.

The next step for the company to evolve from e-procurement to Procurement 4.0 starts with simple actions, seeking to take advantage of the data that the business already collects in a smarter way.

An indispensable concept regarding Procurement 4.0 is the closed loop system, which is characterised by having control of the variable during the process, thus, the system variable in question returns to the beginning of the process and allows changes in the controlled variable, fine-tuning the system results. Another denomination found in the specialised literature for these cases is feedback.

As discussed by Miranda (2005), the concept of identifiability provided by closed loops can be defined as conditions that allow parameter estimation to converge towards parameters that are increasingly closer to the real ones. Also, according to the author, feedback has the action of reducing process variations, making information increasingly reliable. In the context of e-procurement, an intelligent purchasing system would be fed with historical and on-time information regarding the negotiations carried out and in progress for all equipment, materials and services acquired by the company, converging on managerial information about prices and prevailing conditions in the market for such categories.

In the studied company, all orders issued, as well as other proposals participating in bidding processes, are entered into a database that contains the main information such as issue date, supplier, purchased or quoted product, sale price, etc. Thus, in future purchases, the business intelligence tool will present information such as the average price in the market, value of the last acquisition, percentage difference between the values of competitors, other commercial conditions, etc. This information is an important input for the purchasing professional and can serve as arguments at the time of commercial negotiation. In addition, the information provided, supported by the database, will serve as a reference for the formation of internal prices that will be provided to the company's customers in possible competitions in the market.

6.2 Recommendations for future research

Following the theoretical framework of Industry 4.0 technologies (Frank et al., 2019), some recommendations were given to the case-study company:

6.2.1 Smart working

Before adopting new tools, it is necessary to analyse the current scenario of the company's purchasing sector. Many organisations have not structured the control of the purchasing process, keeping the knowledge held only with the professionals involved, without an integrated system to store information. If new technologies are available, it is essential to train the involved professionals in order to feel part of the change.

In addition, Procurement 4.0 is part of the culture of innovation, so that the fulfilment of orders must be based on technological tools that optimise their execution. Nowadays the company has a procurement tool to control and manage the inflow requests which are demanded by the projects teams. Therefore, now it is essential to focus on the outflow data and how to manage it, aiming to turn them into information. This is an important step towards a closed loop system.

6.2.2 Smart supply-chain

Migrating to Procurement 4.0 is a revolution that requires a change in mindset from managers and also from the entire team, since it changes the way to deal with data and information. It requires an agile, creative and proactive posture that the company might not yet have. In a practical example, with an SRM platform, the company would be able to take full control of the supply chain, having all its business and communication relationships handled in one place. Nowadays there are at least four independent systems involved in the company's procurement process though.

When the computerised system indicates the need for a new purchase, the professional responsible for this action can count on the functionality of the computer program to do it. For this, after benefiting from virtual quotations, which are increasingly accessible and viable, the employee issues a purchase order that is sent directly to the supplier, as long as this function has been previously programmed. In addition, it is possible to use electronic contract signatures to sign all contracts with suppliers, streamlining the wait time from 15 days on paper to less than 1 day electronically. These solutions are partially used by the company, however there is a long way to reach Procurement 4.0.

6.2.3 Smart manufacturing and product

The 360° concept aims to ensure that platform users can have a complete view of their process, following the current status and evolution. It would be possible to control and have security and efficiency in the processes of searching for suppliers, contract management, catalogues availability, delivery management, payment publication, evaluation and approval of supplier registration and documents, in addition to having a broad vision of the sector, with smart analysis and full dashboards. This broad information landscape allows implementation of new formats of manufacturing with highly customised demands.

The key point to understand is that Procurement 4.0 consists not only of the adoption of new technologies, but also that the technology itself will not bring results if the company is not open to revisit its current processes and adopt improvements in its processes, in the training of professionals and strategic alignment.

Therefore, it is necessary to remember that it is a whole set of attitudes to ensure the success of the digital transformation of the purchasing sector. Like any project, it is necessary to plan and analyse the current scenario beforehand, and then actually implement technological innovations – which will inevitably drive improvement and gain in current processes.

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