

Bertoncel, Tine; Erenda, Ivan; Meško, Maja

Article

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Best Practices

MANAGERIAL EARLY WARNING SYSTEM AS BEST PRACTICE FOR PROJECT SELECTION AT A SMART FACTORY

Tine Bertoncel^{1*}, Ivan Erenda² and Maja Meško³

^{1, 3)} University of Primorska, Slovenia

²⁾ Group TPV, Slovenia

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Abstract

The purpose of the paper is to contribute to the development of best practices at emerging factories of the future, i.e. smart factories of Industry 4.0. Smart factories need to develop effective managerial early warning systems to identify and respond to subtle threats or opportunities, i.e. weak signals, in order to adapt to an ever-changing environment in a timely manner and thus gain or maintain a competitive advantage on the market. These factories need to develop and implement a several-stage early warning system that is specific to their industry. The aim of our study is, with the help of semi-structured group interviews, to examine which stages of a managerial early warning system are present in the case of a global innovative supplier in the automotive industry. As such, a four-stage managerial early warning system model for a knowledge-based automotive smart factory is proposed, in which aggregate activities and management decision-making strategies are defined for each stage, with the importance of intuition being taken into consideration. We found that managers rely on intuition and extensive analysis for satisficing strategies and teamwork for optimizing strategies, when using their managerial early warning system.

Keywords: managerial early warning system, best practice, Industry 4.0, smart factories, satisficing and optimizing, Slovenia

JEL Classification: D81, D91, O33, L60

* Corresponding author, **Tine Bertoncel** – tine.bertoncel@gmail.com

Introduction

We are witnessing a fundamental transformation of today's business systems toward digital alternatives, along with an emergence of smart factories with cyber-physical systems. This trend is called the 4th industrial revolution or shortened Industry 4.0, which is characterized by an increasingly global business environment, fast and frequent technological changes, which often lead to discontinuities in development (Craig and Douglas, 1996; Day and Shoemaker, 2006; Davis et al., 2012; Leon, 2013; Dobbs et al., 2015; Greengard, 2015; Greenberg et al., 2017; Zhong et al., 2017; Leon, 2018). These factories need to have a high capacity for adaptation, in order to timely adjust and avoid strategic surprises (Day and Shoemaker, 2005; Day and Shoemaker, 2006; Shoemaker and Day, 2009). Management has to be capable of sensing warning signs on the market, which are early indicators of impending impactful events. Digitalization is influencing each segment of our society and increasing importance is given to employing interdisciplinary experts in the field of robotization and digitalization, which is forcing factories to change their business models and employee training programs (Craig and Douglas, 1996; Scheer, 2012; Hansen and Kien, 2015; Dobbs et al., 2015; Arzenšek and Musek Lešnik, 2016; Greenberg et al., 2017).

Literature on the research topic of managerial early warning systems (hereafter referred as MEWS) is scarce, despite its importance for emerging smart factories in Industry 4.0. According to a literature search done by Leon (2013), some authors believe that knowledge-based organizations, i.e. a smart factory, will exist in the future, while others believe that such an organization exists today, as long as it uses the experience, skills and abilities of employees to solve problems for the purpose of decision making. Assuming the latter definition, in today's knowledge-based organization, knowledge is the most important way to gain a competitive advantage on the market. Knowledge can be gathered with information and communications technologies (ICT), however there is also what is called a managerial approach, where employees, who are seen as knowledge workers, solve problems through cognitive-behavioural knowledge gathering for the purpose of optimizing decision making. Some authors consider the managerial approach to be the most important approach and that knowledge workers, as opposed to ICT, are the most important resource a company has (Leon, 2013).

The need for a knowledge-based organization is a response to the rapid and all-encompassing changes that are occurring in an uncertain environment. These fast changes are encompassing all of the global business environment, for example, new technology is emerging at an accelerating rate and the amount of information and knowledge is increasing exponentially, along with being exchanged between individuals worldwide almost instantaneously (Craig and Douglas, 1996; Day and Shoemaker, 2006; Leon, 2013; Dobbs et al., 2015; Greenberg et al., 2017; Leon, 2018). Due to this it is hard to keep up with the change and figure out, for example, what new technology could be important for the long-term success of an organization. This also means that employees must be trained to deal with these kinds of changes. One such system that can help them is a MEWS, which allows the detection of subtle signals early on, in order to prevent threats or to take advantage of opportunities for the company in question (Leon, 2018).

For MEWS in Industry 4.0, a manager that is knowledgeable in smart technologies will be necessary, also known as a chief digital officer, who will as such understand how smart technologies function and why they are necessary for smart factories in Industry 4.0, and will thus be able to detect threatening events, such as the emergence of new technology,

upgrades of existing technology and need for creation of new technology, which when not detected could decrease their company's competitive advantage on the market (Ansoff, 1975; Nikander, 2002; Day and Shoemaker, 2005; Day and Shoemaker, 2006; Shoemaker and Day, 2009; Haji-Kazemi and Andersen, 2013; Hansen and Kien, 2015; Yu et al., 2015; Toma and Naruo, 2017).

1. Managerial early warning systems in knowledge-based organizations

There are three types of MEWS; the first uses statistical tests, the second artificial neural networks and the third uses cognitive and behavioural knowledge gathering techniques and managerial debate. All three of the mentioned MEWS rely on signal detection, where the primary focus is detecting those signals, that are not obvious at first sight and are often ignored as unimportant (weak signals), but can eventually, typically when it is too late, show themselves to be important as a potential threat or opportunity for the organization (Leon, 2018). Although statistical tests and artificial neural networks are objective methods, they often rely on the cognition of those that interpret the data generated by those methods (Leon, 2013; Leon, 2018). These cognitive processes often create biases and heuristics, which can be called bounded rationality (Moser, 1990; Kahneman and Frederick, 2002; Schwartz et al., 2002; Brown, 2004; Day and Shoemaker, 2006; Pesendorfer, 2006; Bearden and Conolly, 2008; Geiger, 2017). Also, it should be noted that none of the MEWS give predictions that are certain, but instead the weak signals detected signify the possibility that an impending positive and negative impactful event is going to occur in the future, whereby managers use their own abilities to imagine and plan future scenarios and create strategies to properly respond to a potential threat or opportunity (Leon, 2018).

1.1. Weak signals

Early warning signals can come in many different forms and can also be non-managerial, as they are often used in all kinds of situation, such as preventing natural disasters or for military use (Gilad, 2003; Trzeciak and Rivers, 2003; Day and Shoemaker, 2006; Martin, 2007; Collins and Kapucu, 2008; Davis and Izadkhah, 2008; Shoemaker and Day, 2009; Assilzadeh and Gao, 2010; Abon et al., 2012; Xie and Liu, 2014; Leon, 2018). For cognitive/behavioral MEWS to work, the company has to become flexible and learn from past experiences, have an open culture, empower and train employees and give them access to more knowledge, among other things (Day and Shoemaker, 2006; Leon, 2013).

Detecting weak signal can signify detecting a trend that at first sight might not seem important for an organization. This trend which can be defined as a new phenomenon, such as the Internet of Things (IoT), being brought into existence from different phenomenon, in the case of IoT this would be embedded intelligence, connectivity and interaction (Tan and Wang, 2010; Schwarz, 2015).

An example of embedded intelligence is a cyber-physical system (CPS), more specifically it is an embedded computer, whose function it is to »monitor and control physical processes, usually with feedback loops, where physical processes affect computations and *vice versa*.» (Lee, 2015, p. 1). While embedded intelligence technology began its development in the early 2000s, after 2006 onward The National Science Foundation (NSF) heavily funded research into cyber-physical systems and later many other institutes and

universities decided to join in on the research. To date, there has been progress in the development of CPS, however CPS are still in their early stage of development (Tan and Wang, 2010; Shi et al., 2011). Connectivity on the other hand means that devices are able to communicate with each other, which can be seen by our ability to connect smart phones to cars and personal computers, however this is what can be considered a human to thing communication (or human to machine) interaction. For IoT to occur, an interaction between things (i.e. thing-thing or machine-machine communication) is necessary, however this will require the capability of holding large amounts of information. According to Tan and Wang (2010) this requires a complete redesigning of the internet, in order to implement IoT on a very large scale.

While IoT and CPS are still in their early stage of development, smart technology still exists and is improving manufacturing. While it might not be too late for some factories to turn into smart ones, those that already have started turning into smart companies have benefited from smart technology implementation (Davis et al., 2012; Zhong et al., 2017). With time, as IoT and CPS technology improves and it becomes more widespread in manufacturing, these technologies might become more of a threat than an opportunity for traditional factories.

1.2. Overcoming bounded rationality to detect weak signals

There are many behavioral MEWS that involve using information processing on an individual and organization level. On the individual level, MEWS deal mainly with overcoming cognitive biases and heuristics that can be due to context-dependent factors that influence decision making (Day and Shoemaker, 2006; Pesendorfer, 2006). These biases and heuristics are often studied by behavioral economists or psychologists (Day and Shoemaker, 2006; Pesendorfer, 2006). Behavioral economics rejects, although not always, rational choice theories of classical economics. Instead behavioral economics proposes that we have bounded rationality, which means that while there can be decision making models and computational strategies, that can be considered rational, as humans we are still limited in our cognitive ability and can often be swayed by emotions, which can result in erroneous and biased judgments. Traditional economic theory does not take into account these biases, because despite the fact that it observes the behaviour of an economic agent, it does not look at how the mind influences and creates those behaviours as behavioural economics would (Moser, 1990; Kahneman and Frederick, 2002; Schwartz et al., 2002; Brown, 2004; Pesendorfer, 2006; Bearden and Conolly, 2008; Geiger, 2017).

Two example, of how our limited cognitive capabilities and often times our emotions can get in the way of judgments, are intuition and working individually on a problem. These two examples can both be influenced through heuristics, biases, lack of critical thinking or imperfect computational ability to optimize decision making (Kahneman and Frederick, 2002). While intuition can also be very useful when decisions have to be made quickly, it does not involve rational analysis and is entirely dependent on quick judgments based on the previous experience of the manager. Day and Shoemaker (2006) stress the importance of an experienced manager's intuition in detecting weak signals. On the other hand, if time is available, it is recommended to complement intuition with rational analysis, however even when there is enough time to do this, our cognitive capabilities can get in the way. It is unrealistic to expect that a single person is able to look at all available problem- solving

options, calculate the utility for all attributes of every option and finally compare all options on the utility of their attributes (Agor, 1986; Kahneman and Frederick, 2002; Brockmann and Anthony, 2002; Patton, 2003; Dane and Pratt, 2007; Cowan, 2008; Bargh and Morsella, 2008; Llinás, 2009; Dörfler and Ackermann, 2012; Suarez-Bobadilla and Love, 2017). As such it might be better for managers to work with other individuals as a group, however working as a group can also have its own negative side effects, such as ignoring important weak signals, as a result of a manager dominating a group-meeting due to his authority. Another option to lessen the burden of doing a solo search for weak signals, is to use alternative ways of gathering information, such as talking to laypeople, global partners, listening to individuals that complain about the services in a company, to name a few (Day and Shoemaker, 2005; Day and Shoemaker, 2006; Shoemaker and Day, 2009; Leon, 2013; Leon, 2018).

In our study we focused mainly on the managerial approach to knowledge gathering, and how MEWS that rely on the experience, skills and abilities of employees, can be considered best practice for gathering important knowledge in knowledge-based organizations. We also looked at how managers overcome the cognitive obstacles to optimal decision making.

2. Methodology

We used purposive ideographic sampling that included a sample size of 5 participants. We conducted group interviews with managers from upper and middle management at a smart factory in Slovenia, who due to their expertise are the most knowledgeable informants on the topic of managerial decision making and early warning system, in regard to smart technology project selection, robotization and digitalization of factory infrastructure. Group interviews were conducted on site in a private setting and have a strictly defined protocol. The interviews were taped using a smart phone voice recorder application and a desk microphone, so as to ensure that all the detail is recorded and can later be transcribed to text. Before the interviews began the interviewees were guaranteed anonymity.

We used a group semi-structured interview method, with the interviews being focused on MEWS, the questions looking at how managers at a smart company interpret weak signals and what kind of MEWS, if any, is present at the factory. We interviewed the managers to find out what kind of decision making strategies they use, for example when do they intuitively make decisions, whether or not they believe that the decisions they make resemble Herbert Simon's satisficing strategies or if they believe they are more similar to the rational decision-making theories of classical economic theory.

The transcribed audio recordings were coded using the methods suggested by Campbell et al. (2013), with the help of the qualitative software analysis program Atlas.ti 7.0. Reliability for in-depth interviews consists of three factors: stability, accuracy, and reproducibility (Campbell et al., 2013). To assure stability, precautions were made so that when a code was used more than once it would refer to the same phenomena each time. For accuracy, a coding system that is considered to be the gold standard is recommended, however to the best of our knowledge none exist for coding managerial satisficing and optimization strategies, as well as MEWS. Finally, for reproducibility, we used the intercoder agreement method by Campbell et al. (2013), which recommends that to increase reliability two or more coders are used to code the interview, in our case we used three, so that the codes can be compared to see if similar codes were used, after which differences should be looked at

and at least a 90% agreement on code use should be reached. Inter-coder agreement was calculated using the formula by Campbell et al (2013), until 100% agreement was reached.

3. Results and discussion

3.1. Four-stage managerial early warning system model (MEWS Model)

The four-stage MEWS based on the case study is proposed. Aggregate activities and management decisions are defined for each stage. The importance of intuition is taken into consideration. The proposed four-stage MEWS model is composed of four steps, each of them relying on intuition to initiate weak signal search, rational analysis and smart technology/ business model implementation (figure no. 1.).

The four steps of MEWS model are as follows:

- *Searching*: this step involves finding weak signals by consulting internal and external intelligences and choosing them with the help of intuition.
- *Sensing*: is mainly concerned with deciding, with the help of intuition and rational analysis, which weak signal will be subjected to extensive computations, in order to determine its profitability.
- *Testing*: involves group analysis of all alternative weak signals, in order to select the optimal signal, and to a degree relies on intuition.
- *(Re)acting*: occurs when the top managers receive the optimal signal selected at the group meeting and approves or rejects it, predominantly with the use of intuition.

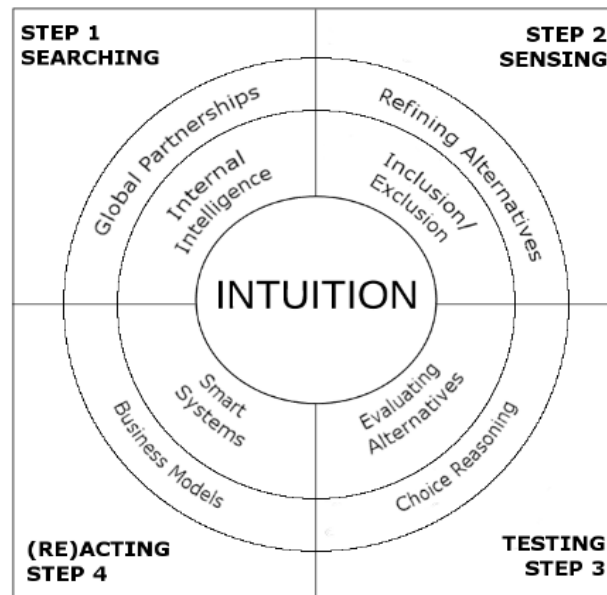


Figure no. 1: Intuition-based MEWS model

3.1.1. Searching

The searching step is mainly based on intuition and is done by managers individually, however without the help of co-workers and business partners, managers at the smart factory would have a much harder time finding weak signals. The usefulness of intuition is largely based on studies finding that it is a very old, albeit sophisticated unconscious processing system that can work without self-awareness, sometimes referred to as System 1 in the dual- processing theory, which can help managers make successful decisions when under time pressure and in crisis situations, whereas System 2 is seen as the rational analysis that can occur after intuition (Kahneman and Frederick, 2002; Patton, 2003; Dane and Pratt, 2007; Cowan, 2008; Bargh et al., 2008; Llinás, 2009). Both System 1 and System 2 have been found to be important in managerial decision making, both of them complementing each other and in their own way helping the manager make decisions (Kahneman and Frederick, 2002; Dane and Pratt, 2007).

By using internal and external resources for information gathering, based on the experience of the manager and the opinion of other knowledgeable informants, a manager can intuitively recognize a technology on the market that shows potential for profit (Shoemaker and Day, 2009). When technology is not available on the market, managers can propose that a technology be developed by the company or with the help of partners. During the searching step, managers make a list of potential technology or technological updates that show promise as a weak signal. During this stage it is possible to say that a manager is satisficing, because they are looking for the first satisfactory and sufficient weak signal, which they then put on their list of potential projects to invest in. The choices are not reasoned and they are not compared with all other alternatives, but are solely chosen based on whether or not the managers intuition tells them that it could be worthwhile to perform computations on them, to determine the actual worth of the weak signal that was selected.

3.1.2. Sensing

In this step managers, as with the previous step, also work individually, however intuition plays a smaller role. This step is composed of including, excluding and refining the alternatives, because due to time constraints a manager has to choose a limited number of potential projects to do calculations on. After it is decided what projects to look at, calculations are made, which can take up to a few weeks to complete. While previous experience is important for intuition and can help with decision making, conscious analysis through critical thinking and mathematical verification is needed for this step, in case the initial intuitive identification was erroneous (Tversky and Kahneman, 1971; Kahneman and Frederick, 2002). The final decision whether a project will be included and refined and presented at the group meeting in step 3 (see figure no 1.), is mainly dependent on how much money it would bring the company in the long run, particularly in regard to the technology's or technological updates ability to shorten production time for manufacturing car components. Once calculations are complete and the project is shown to be profitable, refining commences, which involves looking at how the project is most compatible with the factory or can be improved by utilizing the resources located within the factory. During this step it can be said that the managers are satisficing, because although they have compiled a list of projects, they do not do computations on the whole list, but instead only chose one project (Bearden and Conolly, 2008; Stüttgen et al., 2012)

3.1.3. Testing

After a predicted outcome of the project has been calculated and found to be satisfactory, it is then presented at the end of the month at a group meeting, where each selected project is looked at and first judged intuitively on whether it is better or worse than the others. As with the sensing step, analysis in addition to intuition is performed in order to verify intuition and to determine if additional benefits or flaws can be found in the selected project, along with evaluating all other alternatives to make sure no mistakes were made in choosing the preferred alternative. Working in groups gives the managers the benefit of different expert perspectives on a single project. Finally, when a project is selected as the optimal choice, a proposal is written where reasoning is given for why the project was chosen. The third step can be considered an optimizing step, due to the fact that all compiled alternatives are compared to each other on their attributes and the optimal one is chosen.

The teams that are involved in decisions about projects are subdivided into different branches of interdisciplinary experts that are well versed in the technological needs of the factory. One of the main reasons these teams are formed is to prevent monetary losses from occurring, so at the end of the month all of these branches meet up, update each other and plan future actions. If the project is very important and big then even the top managers are involved in that meeting, especially when the investments are in the range of hundreds of thousands or millions of euros. In addition to the process of selecting projects that will go through complex computations, we also believe that selecting members for a project falls under the category of satisficing, since we were told that experts from fields such as quality control, maintenance, production and technology, are included based on whether or not there is sufficient “chemistry” between a group member and the rest of the group. This is in line with previous findings showing that it is important for the manager to have good social skills (Leon, 2013).

While the team as a whole does optimize, they are still composed of “administrative men”, who are limited in their cognitive computational abilities, to the extent that humans are (Brown, 2004). As such the “administrative man” goes for the easier solution, which is to go for the first satisfying and sufficient (satisficing) solution to a decision-making problem within a factory, because finding the optimal alternative would be too cognitively demanding. In light of this, the team as a whole can be viewed as an “economic man”, whereby together they use an optimization strategy and are thus capable of very complex calculations, which no human could achieve alone within the time restrictions, demanded by the factory’s need to stay competitive on the market (Brown, 2004). However, “administrative man” might not be the best word to describe each member of the project, as they have to do complex computations that take days or weeks to complete, to put one project on the list for the team meeting at the end of the month, instead “optimal satisficing” might be a better term to use (Bearden and Conolly, 2007; Bearden and Conolly, 2008).

3.1.4. (Re)acting

The proposal from the previous step is then forwarded to top managers, who then approve the project based on their intuition, which results in business model adjustment and smart technology implementation. This part depends on whether or not the optimal project chosen

during the testing stage is deemed worthwhile by top managers. Since top managers are under a lot of time pressure, they make a judgment that is mainly done by intuition, as opposed to the sensing and testing steps of the early warning system, which also heavily rely on rational analysis. This makes sense, since the latter two steps can take weeks to complete.

The final stage could also be considered to be a satisficing strategy, where the manager looks at one proposed project at a time and decides on the first one that is satisfactory and sufficient, because due to time pressure he does not have time to do long computations looking at all alternatives.

3.2. Project selection at a smart factory

Project selection at a smart factory occurs during the project search part of the MEWS and is done through implemented pyramid showing which aspects are important, with the top of the pyramid being most important and bottom least important (figure no. 2).

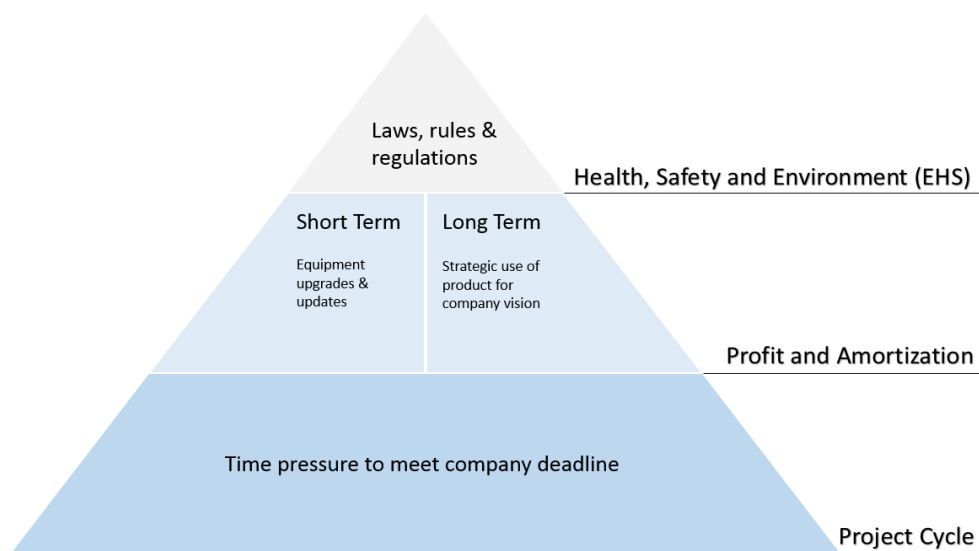


Figure no. 2: Importance of criteria for approval of project selection

The most important criteria for whether or not a project will be chosen is if it fulfils the environmental, health and safety concerns required of companies. The second most important factor is whether or not the project is economically justified, firstly how long it will take for return on investment to occur in the short-term for upgrades and updates of equipment, secondly for long-term investment the factory product is important and its strategic use for the vision of the factory. Short-term and long-term returns on investment are evaluated based on knowledge of the market and previous experience on whether or not such a choice is economically justified. Some teams have other criteria, but the managers we interviewed are only concerned with monetary gain. For example, the costs of a project are looked at in regards to how much profit there will be for each attribute and how long it will take to recover costs. The benefit of only looking at the monetary value for all

attributes is that you can combine all of the values and get a single number, the total sum of money a project will bring in a given amount of time, which can then be easily compared to other projects. For example, the amount of money made by speeding up a process by a few seconds is calculated, along with how long it will take this faster production to cover the costs of investment. The managers told us that even half a second can make a big difference in their factory, if thousands of parts are made each day, while at other times a gain of a few seconds is not worth it, since only a few of those parts are made per day. Sometimes an old technology is sufficient, and no update or upgrade are required, but at other times new technology is needed due to new and better technology appearing on the market, often on a yearly basis. The final criterion is if it meets the time pressures to meet deadlines, which can be trumped by both an economically justified, environmental, health friendly and safe project. With new technology optimization is a must and is most crucial when dealing with new welding or lacquering technologies, because otherwise the company might lose their competitive advantage as a smart factory. However, sometimes an optimal project is declined, if there is not enough money to invest and if there is not enough time to meet a deadline for its funding.

3.3. Decision making at a smart factory

Satisficing occurs during the project search part of the MEWS and is done on an individual level, while optimizing is done on a team level, whereas the final optimized decision is again individually approved by a top manager (figure no. 3).

We found that the managers we interviewed were in charge of projects that dealt with the production of automobile parts. These managers were involved particularly in technology that is used for the automatization of manufacturing, i.e. smart technology. They state that although some processes are now fully automatized and do not need human surveillance and control, there is still a lot of activities that are completely done by hand and that most of those that are robotized or digitalized need a human to give them correct input to carry out their task properly. Overall they believe that automatization decreases mistakes that are commonly made by humans and that it makes the job of the worker easier. Decision making on which project for smart technology to select, is based on a system the managers call EPDC, which monetizes project criteria to see if they meet the required yearly profit margin. If the project is selected, its progress is constantly monitored, in order to see if there is any hold on a project.

With new technology, optimization is a must and is most crucial when dealing with new welding or lacquering technologies, because otherwise the company might lose their competitive advantage as a smart factory. However, sometimes an optimal project is declined, if there is not enough money to invest and if there is not enough time to meet a deadline for its funding.

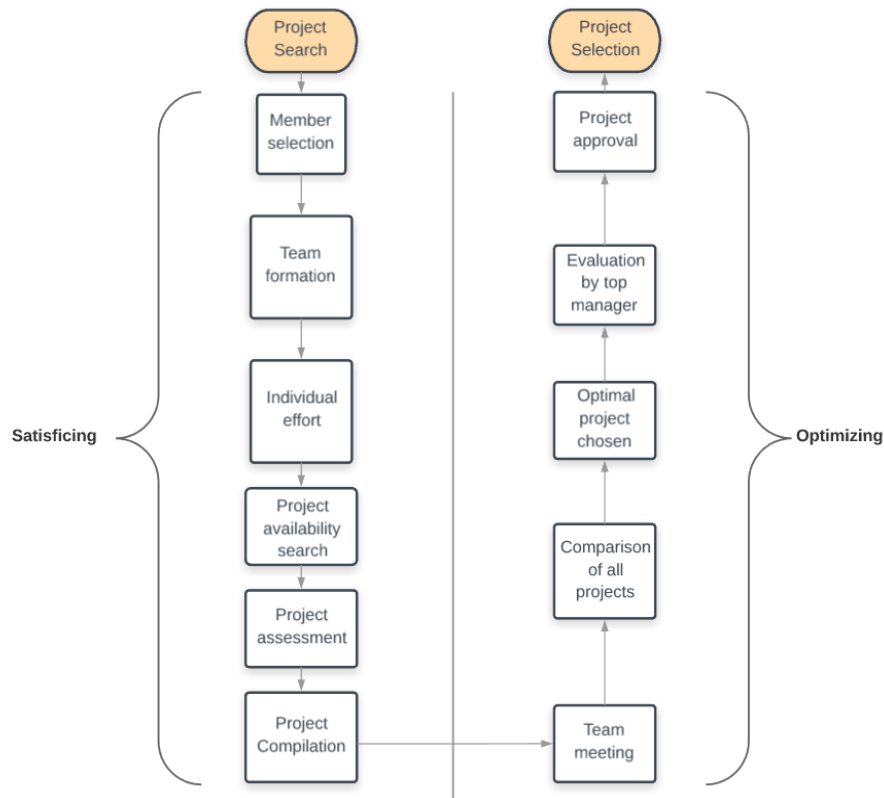


Figure no. 3: Satisficing vs optimizing decision making at project selection

Conclusion

In our study we found that a MEWS is used at a smart factory and that it relies to a high degree on intuition, particularly in its initial and final step, and that it requires group effort, along with extensive rational analysis. We also found that both satisficing and optimizing strategies are used, with satisficing being found in the first, second and final step, with the third step resembling an optimization strategy. MEWS model can help provide insight into complicated and very important aspects of a manager's routine and can be used to train managers in strategic decision making, thus serving both a descriptive and prescriptive model. In our study, we found that a smart factory in Slovenia can benefit from having a MEWS to detect subtle threats, as well as obvious ones, before they happen, which reflects previous research (Day and Shoemaker, 2005; Day and Shoemaker, 2006; Shoemaker and Day, 2009). Further studies should be conducted to see whether or not other smart factories have similar MEWS and to learn more about how they have helped them compete on the market in the past.

There have been many choice models done for both satisficing and optimizing that attempt to address three problems inherent in rational choice theory (González-Valdés and de Dios Ortúzar, 2018). The first one is that multiple comparisons by a single individual, for all of the attributes for every choice available, does not seem realistic. The second problem states that information gathering is costly, in regards to money, time and effort (González-Valdés and de Dios Ortúzar, 2018). The proposed MEWS model overcomes the first obstacle in choosing an optimizing strategy, by putting the responsibility on multiple individuals, along with the utility for all attributes of a single option adding up to a single monetary value. The use of a single monetary value likely lessens the time and effort put into optimizing, however it is hard to say whether it also lessens the monetary costs. The final problem with optimizing, is the inherent difficulty in assigning a common utility value to different attributes (González-Valdés and de Dios Ortúzar, 2018), however in the case of the studied smart factory, all attributes are equally important and the deciding factor is only how much money they are expected to bring to the company, given that the safety, health and environmental demands are met.

A lot has changed since the time of Herbert S. Simon and while his theory of bounded rationality might still hold, not attempting to overcome these cognitive limitations might lessen the advantage of a company in today's competitive market, in our case that of smart factories. Instead we propose that smart factories look for solutions to problems that bounded rationality poses for their needs, such as group effort from a team of interdisciplinary experts that work together to find the optimal solution in cases such as smart technology selection.

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