Scenario planning combined with probabilities as a risk management tool – analysis of pros and cons

Helena Gaspars-Wieloch

Department of Operations Research,
Poznan University of Economics and Business,
Al. Niepodleglosci 10, 61-875 Poznan, Poland
Email: helenagaspars@poczta.onet.pl

Abstract: Scenario planning and probabilities are often very helpful in uncertain decision problems. In the paper, we examine the correctness of combining probabilities with scenario planning in risk management. We make a literature review and analyse diverse decision problems differing from each other with regard to their nature, the decision maker's objectives and preferences. We explore competition, quality, innovation, resource allocation, inventory and banking issues. The illustrative examples concern both one-criterion and multi-criteria decision problems. We get to the point that scenario planning is an unquestionable support for risk management. Nevertheless, the use of probabilities as an accompanying tool may be necessary and justified merely in some specific cases.

Keywords: scenario planning; probabilities; risk management; risk assessment; uncertainty; payoff matrix; scenarios; decisions; banking; saving rates; spare parts quantity problem; product quality; innovations; coefficient of pessimism.

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Biographical notes: Helena Gaspars-Wieloch is a member of the Department of Operations Research in the Poznan University of Economics and Business. Her research interests: operations research, decision-making under uncertainty, project management, multi-criteria optimisation, algorithms and heuristics.

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1 Introduction

Risk management (RM) includes the identification, evaluation and prioritisation of risks. It consists in minimising, monitoring and controlling the probability or impact of unfortunate events, or in maximising the realisation of opportunities (Hubbard, 2009). One of the methods designed for risk identification is the scenario-based risk identification.

Scenario planning (SP) is a tool frequently used in the decision-making process. It is very helpful when the decision maker (DM) deals with issues under uncertainty, i.e., situations where at least one parameter of the decision problem is not deterministic (DMU – decision making under uncertainty). The ability to predict future economic events is undoubtedly crucial to the maintenance of successful business activities (Aras et al., 2017). Recently, Hoffmann (2017a) has prepared an interesting work where he discusses advantages and shortcomings of SP as a RM tool.

Our contribution also deals with these issues, but here we formulate a question 'Is it worth combining SP with probabilities in RM?'. Probabilities may of course facilitate the choice of the final decision variant since they make the uncertainty less 'uncertain', but in this article we focus on their role in SP and make an attempt to examine the correctness, strengths and weaknesses of combining SP with probabilities within the framework of RM problems. There problems are indeterministic on account of the unknown future phenomena (Vilkkumaa et al., 2018) and ever-changing markets (Aras et al., 2017). The need to meet the demands of an evolving business environment is also underlined for instance in the *Enterprise Risk Management – Integrated Framework* which was published by the COSO board in 2017 (COSO – Committee of Sponsoring Organizations of the Treadway Commission). According to this document the uncertainty accompanying RM problems results, among other things from the increasing business complexity.

From a practical point of view, it is obvious and unquestionable that both SP and the use of probability can separately make RM very effective. In The Wall Street Journal (2019) we can find numerous advantages of SP – it 'helps organisations perceive risks, warning signs and opportunities more broadly, (…) spot sources of risk that may otherwise go undetected, (…) point to useful strategies and risk mitigation tools, (…) start identifying trends that are shaping the future as well as forces that cannot be predicted and influenced'. The same is valid for the use of probability. It also plays an essential role in RM since it allows us to evaluate particular risks within the probabilistic risk assessment (PRA) which consists in characterising risks by two quantities: the severity of possible consequences and the probability of occurrence of each consequence (Wreathall and Nemeth, 2004). Nevertheless, the goal of this research is to check whether and when it is worth assigning probabilities to each scenario within SP. The results of such an investigation may help practitioners plan the RM process properly, i.e., apply SP with scenario probabilities (if justified), or use it without such additional data (if suggested).

Hence, the aforementioned analysis will enables detecting circumstances where the use of probabilities in scenario-based RM is appropriate and situations where we advise one against it. The contribution constitutes a review of opinions already described in the literature as well as a collection of many new conclusions and recommendations.

The research methods supporting the achievement of our objective involve a literature survey, simulations and the analysis of six diverse decision problems related to RM:

1 How to reduce the risk of losing customers?

2 Which technology should be chosen to diminish the risk of a decrease in the quality of a totally new product?

3 What employment strategy implement to maximise the performance of the RM team?

4 How many spare parts to buy in order to minimise losses?

5 How the order quantity should change in the case of one device?

6 Which saving rates strategy should the bank introduce so that the risk impact is the lowest?

Within the literature survey we compare diverse standpoints concerning the assignment of probabilities to particular scenarios and formulate general conclusions on its legitimacy. The comparison is based on theoreticians' and practitioners' opinions. When investigating specific RM situations presented by means of simple illustrative examples we make an attempt to verify whether the probability application to SP is always justified. The examples differ from each other not only with regard to the main goal and constraints, but also in terms of the DM's knowledge and preferences (predictions and assumptions). We intentionally study the decision problems enumerated above as they are related to significantly different domains and concern different companies: customer loyalty and demand (e.g., Lidl, Walmart, Costco), innovations (e.g., Apple, Google, Amazon), resource allocation (e.g., Lego, Rolex, BMW), inventory strategies (e.g., Nissan Motor, Honda Motor, Bosch), banking policy (e.g., BNP Paribas, Citibank, Deutsche Bank AG). This variety of decision situations is the best evidence that RM abilities are wanted and valued in numerous companies, projects and areas. The empirical analysis allows us to formulate new statements on the usefulness of probability in SP.

The work continues the topics raised in two papers:

1 Strengths and weaknesses of scenario planning as a risk management tool (Hoffmann, 2017a).

2 Should probabilities be used with scenarios?' (Millett, 2009) Where the author discusses the pros and cons of using probability data in SP.

The authors' insights are interesting, inspiring and certainly extremely helpful for DMs, but in this work, we would like to also offer our reflections on that issue by referring to other facets.

The paper is organised as follows. Section 2 briefly presents the essence of RM. Section 3 describes SP, payoff matrices, different probability definitions and discusses possible relationships between SP and probabilities depending on the level of uncertainty considered. This part of the contribution also quotes diverse standpoints on the role of probability in SP. Section 4 analyses fictitious RM problems illustrated by means of payoff matrices. Conclusions are gathered in Section 5.

2 Essence of RM

There are numerous definitions for the term 'risk' (Aven, 2016; Fishburn, 1984; Pfeffer, 1956; Waters, 2011). One of them is as follows: the risk is the possibility that an event will occur and adversely affect the achievement of an objective (Dominiak, 2009). As it was mentioned in the introduction the goal of RM among other things, is to identify and assess risks and minimise their impact (COSO 2017 *Enterprise Risk Management – Integrated Framework*). RM consists in handling first risks with the greatest loss and probability of occurring while the remaining threats are handled later. Risks may be connected for instance with uncertain financial markets, project failures, liabilities to banks and suppliers, accidents and disasters. Risk sources can be diverse: weather, prices, employees of the company, competition strategies, innovations, etc. (COSO 2017 *Enterprise Risk Management – Integrated Framework*). Note that risks are usually called 'negative events'. On the other hand, 'positive events' mean opportunities. The ability to manage risk is useful for example in security, engineering, actuarial assessments, information technology, financial portfolio constructing, public health and safety, and enterprise, project or megaprojects management (Virine and Trumper, 2007). Project Management Institute (PMI) states that project management knowledge draws on ten areas (time, cost, quality, procurement, etc.) and one of them is just project RM. There are four main strategies to manage threats (so-called risk treatments):

1. avoid/eliminate them
2. reduce their impact/probability
3. transfer threats to an other party
4. retain their consequences (Dorfman, 2007; Greene and Stellman, 2009; Roehrig, 2006).

Risk can be managed according to a proactive or reactive approach (Rasmussen and Svedung, 2000). The goal of the proactive RM is to improve organisations' abilities to avoid or manage existing and emerging risks. Thus, it helps adapt quickly to unwanted events. The reactive RM simply involves the ability to respond quickly to risks that have already occurred. According to the International Organization for Standarization (ISO), RM is supposed to satisfy many conditions (e.g., it should create value, be an integral part of organisational processes, be systematic and dynamic, be based on the best available information and take human factors into account).

The most known risk identification methods are taxonomy-based risk identification, common-risk checking, risk charting, objectives-based risk identification and scenario-based risk identification. The last procedure is particularly significant for us since this work just concerns SP. The risk identification is followed by a qualitative and quantitative risk assessment (Wreathall and Nemeth, 2004) during which one estimates risk potential severity of impact (e.g., damage, loss) and its probability of occurrence (which is also an issue discussed in the contribution). Risk identification and risk assessment are often supported with such tools as Ishikawa diagrams (cause-and-effect diagrams, fishbone diagrams), decision trees, Pareto analysis, impact and probability matrices and risk heat maps (Greene and Stellman, 2009).

Both stages are usually quite complex and difficult due to the lack of sufficient knowledge, but they enable risk quantification (e.g., by multiplying impacts by the probability) which is extremely vital – it allows senior executives of the organisation to prioritise RM decisions.

We would like to underline that although one of the four main risk treatments consists in reducing the risk probability, the work does not discuss ways of threat probability decreasing, but it concerns the legitimacy of applying the likelihood to SP in RM.

3 SP and probabilities

Let us analyse the essence of SP and the role of probabilities in a more detailed way.

SP supports uncertain decision-making and the identification of risks understood as uncertain and uncontrolled factors influencing the consequences of chosen strategies. It is useful for government planners and military analysts, companies, scientific communities, futurists and educational institutions (Mietzner and Reger, 2005; Ringland, 2006; Silber, 2017). It supports e.g., sales forecasting, projects selection or inventory management. The target of SP is to construct scenarios describing possible ways in which the future might unfold (Gaspars-Wieloch, 2019b). The scenarios may represent the alternative methods to achieve an objective or an analysis of the interaction of forces. Events that trigger undesired scenarios are identified as risks. Diverse definitions of the term *scenario* and numerous guidelines concerning a correct scenario construction are provided for instance in Chermack et al. (2001), Dominiak (2006), Pomerol (2001), Ravindran et al. (1987), Schoemaker (1995) and Wright and Goodwin (1999).

Project managers eagerly use SP since it allows one to analyse problems in a more deterministic way (Schoemaker, 1995) than for example continuous probability distributions or fuzzy numbers (Durbach, 2014; Maciel et al., 2018). The strength of the scenarios is that they do not consider just one future, but multiple potential futures (Hoffmann, 2017a). Thanks to SP the organisations are better prepared to handle new situations and promote proactive leadership initiatives because it recognises technological discontinuities or disruptive events and includes them into long-range planning. SP improves the organisational learning and the decision-making process since the aims, opportunities, risks and strategies are then shared between the participants (Mietzner and Reger, 2005).

Hoffmann (2017a) stresses that the future is invariably a combination of the known and the unknown or unknowable, but the proportion of the latter tends to rise as the time-scale extends. That is why, although SP is a more modest method than exact probability-based risk measurement methods, 'identifying a range of versions (scenarios) of what might happen' can be a tenable and supportable basis for risk and planning analysis, especially given the fact that SP accepts uncertainty, unpredictability and vagueness, i.e., three main features of the future. Hoffmann (2017b) emphasises in his book that the probability theory is inadequate for modelling systematic and extreme risk in a banking context.

According to Probst and Bassi (2014) scenarios nurture innovative thinking about possible future behavioural paths of the systems. They also support the learning process (Van der Heijden, 1996). The team SP allows avoiding common errors and biases like overconfidence, misjudgement and tunnel vision (Schoemaker, 1995).

SP also has opponents stressing that it requires a deep understanding and knowledge of the field under investigation, which entails a very time-consuming selection of suitable experts with sufficient skills to collect, interpret and monitor data from different sources (Mietzner and Reger, 2005). If people cannot develop and apply SP properly, this method becomes useless. Probst and Bassi (2014) add that the SP team is obliged to generate plausible scenarios and continuously revise them. They also reveal that SP is inadequate for decisions made in the short-term. Other serious disadvantages of SP are highlighted in Hoffmann (2017a), who draws to a conclusion that it offers some orientation only due to the aforementioned vagueness, and in Roxburgh (2009), who notices that scenarios do not cover the full range of future possibilities.

Table 1 Payoff matrix with single values

Scenarios (nature)	*Decisions (decision maker)*				
	D_1	…	D_j	…	D_n
S_1	$a_{1,1}$	…	$a_{1,j}$	…	$a_{1,n}$
⋮	⋮	⋱	⋮	⋱	⋮
S_i	$a_{i,1}$	…	$a_{i,j}$	…	$a_{i,n}$
⋮	⋮	⋱	⋮	⋱	⋮
S_m	$a_{m,1}$	…	$a_{m,j}$	…	$a_{m,n}$

Source: Gaspars-Wieloch (2019b)

The effects of SP can be presented by means of payoff matrices showing the results influenced by the chosen decision (alternative, strategy, variant, option) and the scenario occurring in the future (Gaspars-Wieloch, 2015a, 2018a, 2018b). The outcomes in the payoff matrix may be given in the form of single, definite numbers (Table 1) or intervals (Gaspars-Wieloch, 2019b). Symbol n denotes the number of alternatives (decisions that we can choose and perform), m is the number of scenarios (situations that may take place and are independent on our activities), $a_{i,j}$ signifies the payoff gained if decision D_j is selected and scenario S_i occurs. For a more uncertain background it is recommended to replace concrete payoffs $a_{i,j}$ with intervals consisting of endpoints (limit points) $a_{i,j(\min)}$ and $a_{i,j(\max)}$. They are the minimal and maximal possible outcome, respectively. All the considered ranges are closed (both endpoints are included in the intervals): $<a_{i,j(\min)}, a_{i,j(\max)}>$. It is possible to directly transform each payoff matrix into a decision tree. Payoff matrices can be used in one-criterion and multiple criteria management and optimisation, but when considering more than one objective, each target needs a separate outcome matrix (Gaspars-Wieloch, 2017e).

It is worth underlining that SP has also a psychological and behavioural aspect since payoffs may be estimated by experts, DMs or people being both experts and DMs. In the first approach the outcomes are generated in the most objective way while the second approach may lead to the most subjective predictions. Regardless of the estimation method it is suggested to convert initial values into numbers reflecting the DM's preferences (utilities) (Ravindran et al., 1987).

The form of the payoff matrix is closely connected with the uncertainty degree (level) of a given problem (Cannon and Kmietowicz, 1974; Gaspars-Wieloch, 2017a, 2017b, 2019a; Guo, 2014; Haimann et al., 1985; Kaplan and Barish, 1967; Knight, 1921; Kofler and Zweifel, 1993; Ravindran, 2008; Urli and Nadeau, 2004; Vilkkumaa et al., 2018; Waters, 2011). In the case of uncertainty with known probabilities (UKP – I level) the DM (or expert) is able to define possible scenarios, estimate the likelihood of the occurrence of each of them and calculate the expected value for all the alternatives. Hence, the payoff matrix contains then a supplementary column with probability values. The table with outcomes can even consist of $2 \times n$ columns if particular decisions are characterised by different probability distributions. Uncertainty with partially known probabilities (UPKP – II level) signifies that the DM is capable of setting possible events and their order, starting with the most probable and ending with the least probable scenario. A partial knowledge may also occur when the likelihood is presented as intervals (instead of precise values). Uncertainty with unknown probabilities (UUP – III level) concerns the situations where one can only predict future scenarios. The information about the probability distribution is not available, however the DM is allowed to declare his/her attitude towards risk, i.e., a subjectively estimated possibility that some bad, or other than predicted, circumstances will happen. That can be done for example by means of the optimism or pessimism coefficients which make up a kind of probability-like quantities (Gaspars-Wieloch, 2017a) and refer to behavioural economics (Askari and Refae, 2019). Total ignorance (TI – IV level) includes all the situations where the DM is not capable of defining future scenarios, which means that such uncertain problems cannot be presented on the basis of payoff matrices.

Before we present diverse points of view related to the usefulness of probability in SP, we would like to briefly examine its meaning, which is not so simple since there are numerous, often contradictory, probability definitions (Aven and Reniers, 2013; Frechet, 1938; Davidson, 1991). The probability is usually understood as the extent to which something is likely to happen or be the case. It is a measure with numbers between 0 indicating impossibility and 1 signifying certainty. Note that the probability values vary over time because they depend on our knowledge. The most known probability definitions and theories are as follows:

1 classical probability definition (Laplace, 1812)

2 geometric probability definition

3 frequentist probability definition (von Mises, 1957)

4 prior, posterior (conditional) and inverse probability

5 propensity probability definition (Popper, 1988)

6 measurable and unmeasurable probability (Knight, 1921)

7 Kolmogorov probability theory (Kolmogorov, 1956)

8 objective and subjective probability (de Finetti, 1975)

9 logic probability definition (Carnap, 1950).

For example, according to the propensity theory, the probability is the tendency of some experiment to yield a certain outcome, even if it is performed only once. All the aforementioned definitions have been concisely described in Gaspars-Wieloch (2019b) where the author concludes that:

1 a unanimous and universal probability interpretation does not exist

2 the majority of probability definitions were called into question by a lot of writers (Caplan, 2001; de Finetti, 1975; Frechet, 1938; von Mises, 1949, 1962; Ville, 1939).

The definitions are criticised for instance for using the word ‘probable’ (see classical probability definition), the lack of a sufficient number of historical data (see frequentist probability definition) or the necessity to use a bounded set of possible events (see geometric probability definition). de Finetti (1975) emphasises that regardless of the information we have, a scientific method enabling the assignment of probabilities to scenarios does not exist as the likelihood is just an opinion of a given person. von Mises adds that the probability of a single event should not be expressed numerically as probabilities only concern repetitive situations which are not frequent in real problems (Guo, 2014)!

The last question that we would like to investigate in this section concerns the usefulness of probabilities in SP. This issue is the object of interest of many researchers. Opinions differ (Grienitz et al., 2014; Mandel and Wilson, 1993; Michnik, 2013; Millett, 2009; Montibeller and Franco, 2010; Ralston and Wilson, 2006; Ramirez and Selin, 2014; Ravindran et al., 1987). The authors evaluate the role of the probability distribution depending on different aspects, e.g., the essence of SP, the individual or group decision-making, the facilitation in decision-making, the flexibility in decision-making.

Some of them are convinced that there are many advantages of using objective or subjective probabilities in SP (Millett, 2009; Ravindran et al., 1987). From their point of view the likelihood is its inherent element since it facilitates and improves the whole decision-making process. Millett (2009) stresses that this application is justified if the following conditions are satisfied:

1 the corporate culture prefers quantitative or quasi-quantitative methods to purely qualitative reasoning

2 the scenario team is familiar with the concept of Bayesian probabilities

3 there is enough time, resources and budget to prepare analytical scenarios with probabilities.

Other researchers do not support combining the likelihood with SP (Michnik, 2013; Montibeller and Franco, 2010) since within SP the set of events does not need to be exhaustive, however it is a required main characteristic of the Kolmogorov probability theory. When discussing that topic it is worth emphasising that some scientists do not consider scenarios and states of nature as the same thing (Durbach, 2019). They treat the states of nature as mutually exclusive and collectively exhaustive, which entails the possibility to assign probabilities to each of them. On the other hand, the scenarios do not have to fulfil that condition. Therefore, they should not be combined with the likelihood. Nevertheless, the literature offers contributions where the scenarios are equivalent to the states of nature. Such a probabilistic approach aggregating scenarios is applied for instance in Levary and Wan (1999) and Vilkkumaa et al. (2018). However, this method is not accepted by Stewart et al. (2013) who draw to the conclusion that since the set of scenarios does not constitute a complete probability space, scenario 'likelihoods' are not probabilities! The states of nature, in contrast to scenarios being incomplete descriptions (e.g., the first scenario may concern politics, the second one may focus on economic aspects and the third one may concentrate on weather factors), are constructed from the same underlying dimensions.

Ramirez and Selin (2014) add that "an uncomfortable pause, staying with ambiguity and delving into ignorance may be of more value than a decisive judgement in this regard". Grienitz et al. (2014) suggest developing scenarios without probabilities and focusing on the most important event. A similar approach can be found in Gaspars-Wieloch (2015b), where it is recommended to focus on one event or a significantly reduced set of previously expected scenarios.

Durbach (2019) is another opponent of combining SP with probabilities. In his opinion the likelihood application is a too onerous task and might negatively affect ease of use and transparency. He states that SP should be treated as a means of reducing complexity and managing strategic uncertainties that may be difficult to express probabilistically. Durbach (2019) makes an attempt in his article to answer to the question 'how to aggregate performance over different scenarios to arrive at a global evaluation of alternatives'. He distinguishes three possible approaches:

1. do not aggregate scenarios at all
2. treat them as states of nature and use probabilities
3. treat them as dimensions over which the performance can be compared.

He supports the last one only. That is why, instead of probabilities, Durbach (2019) applies relative importance of scenarios in his scenario-based procedures.

It is worth mentioning that some scenario practitioners (Shell, SRI International and GBN) have also objected to the use of probabilities. They claim that:

1. the scenarios should be used for identifying possible and preferred futures, not likely futures
2. all the scenarios ought to be considered equally likely so that plans will be developed for each scenario
3. 'the use of probabilities implies too much precision and distracts from the storytelling qualities of scenarios – scenarios are the most powerful when they stimulate flexible and innovative thinking about the future'
4. the forecasts may identify trends, but they are not able to capture the discontinuities of change that come from intuition, imagination and the story qualities of scenarios
5. the scenarios ought to be created by teams, but teams cannot reach agreement on probabilities of occurrence – the use of probabilities would compromise the team-building benefits (De Geus, 1988; Fahey and Randall, 1998; Mandel and Wilson, 1993; Ralston and Wilson, 2006).

In this section we have quoted supporters' and opponents' standpoints and actually all the justifications seem to be rational.

4 Illustrative examples of scenario-based RM – discussion

Now, it would be desirable to investigate specific RM areas and check how SP supports them. We are going to analyse the strengths and weaknesses of applying probabilities to SP in RM problems. The target of this section is to examine diverse decision situations presented on the basis of simple illustrative examples, but we do not concentrate on determining a final solution for each considered problem.

The *first example* (*1*) concerns company A which has just performed the risk identification stage and predicts a significant reduction of customers resulting from new decisions made by the competing operators. Our company has chosen the second strategy managing threats, i.e., reducing risk impact. The enterprise is considering six possible solutions:

1. lower product prices by 10%
2. lower product prices by 15% and decrease product quality
3. keep prices stable and increase product quality

4 change the location (50 km)

5 change the location (150 km)

6 modify the product portfolio (assortment).

The company intends to use SP in order to check how particular alternatives affect the number of customers.

Table 2 Example 1 – change in the number of customers – fictitious data in thousands of people

Scenario	*Strategies reducing risk impact*					
	D_1	D_2	D_3	D_4	D_5	D_6
S_1	<–5, 0>	<–3, +4>	<+5, +8>	<–15, –10>	<–20, –10>	<+20, +35>
S_2	<–10, –7>	<–5, 0>	<+1, +4>	<–30, –22>	<–5, +5>	<0, +10>
S_3	<–20, –14>	<–35, –25>	<–40, –30>	<+10, +18>	<0, +15>	<–30, –20>
S_4	<+10, +16>	<+15, +20>	<0, +5>	<+25, +35>	<+10, +25>	-
S_5	<+4, +8>	<+10, +13>	<–5, –2>	-	-	-

Source: Prepared by the author

Note that the scenarios given in Table 2 do not represent possible company responses. They show potential nature reactions. As we see, the analysed strategies can be categorised in three groups since the first one involves decisions related to prices and quality, the second one includes alternatives connected with the company location and the third one contains one option concerning the modification of the range of products. Therefore, the set of scenarios is different (in number and composition) for each group of decision variants! It means that in the case of the likelihood estimation for particular events, probability values should be defined separately for each group of strategies. We can also observe that the change in the number of clients is not given in the form of precise values, but by means of intervals, which may result from the insufficient experts' knowledge about the consumers' behaviour and preferences. Additionally, we notice on the basis of the value ranges that the scenarios taken into account do not constitute a complete probability space.

Suggestions (example 1): the two last observations (lack of adequate expert knowledge and incomplete set of scenarios indicate reasons why a probability distribution should not be assigned to the payoff matrix presented in Table 2.

In the *second example* (*II*) we investigate company B which intends to launch a totally new product within an innovation or innovative project (Gaspars-Wieloch, 2017c, 2017d). We assume that the innovation products bring new products and new services, while the innovative projects are projects managed on the basis of new methods (Spalek, 2016). The enterprise wants to implement one out of five technologies, but each of them is risky and may affect the planned product quality. Furthermore, each procedure depends on a different set of scenarios, i.e., threats (Table 3).

Table 3 Example 2 – final product quality (in comparison with the planned level of quality) – fictitious data in percent

Scenario	*Strategies (technologies)*				
	D_1	D_2	D_3	D_4	D_5
S_1	90%	60%	15%	80%	20%
S_2	80%	75%	30%	85%	70%
S_3	30%	90%	10%	15%	30%
S_4	-	-	100%	0%	75%
S_5	-	-	0%	-	-

Source: Prepared by the author

Note that the scenarios given in Table 3, again, do not represent possible company responses. This time, they take into consideration potential risks (threats) linked to such factors as the timeliness of deliveries, the quality of raw materials, the foreign exchange exposure, the productivity of the workforce, the repayment of receivables and so on. Moreover, particular technologies depend on different sets of scenarios. The experts are capable of estimating precise values, but in connection with the fact that the product is totally new, there are no historical data on the basis of which the rate of occurrence could be determined.

Suggestions (example 2): hence, the frequentist probability definition cannot be applied (lack of historical data). The use of subjective probability is also questionable because the considered product has not been created before.

Table 4 Example 3 – annual profit – fictitious data in thousands of euros

Scenario	*Strategies (number of employees)*				
	D_1 – 10	D_2 – 20	D_3 – 30	D_4 – 40	D_5 – 50
S_1	120	150	145	140	100
S_2	800	900	950	900	750
S_3	90	90	80	70	55
S_4	–1,050	–800	–400	–500	–1,100

Source: Prepared by the author

Now, let us discuss the problem of resource allocation (example 3). Company C tries to estimate future annual profits depending on the increasing number of employees involved in RM (Table 4). The scenarios represent here situations differing from each other in terms of the efficiency of the RM team and the environment impact. The task seems to be quite simple since in this case we assume that company C provides traditional services, well-known by managers, workers and experts, which means that their knowledge and experience may contribute to a rather realistic quantification.

As the payoff matrix estimation is not onerous, the probability assignment could be performed in this case. Nevertheless, people are not willing to define the likelihood because they anticipate some new little known phenomena, which do not result from their past observations.

Suggestions (example (3): perhaps, instead of the objective or subjective probabilities (which are not recommended when a change of the trend is expected), the use of some probability-like quantities would be appropriate here. One of them is the pessimism coefficient allowing one to declare the attitude towards risk. This parameter was introduced by Hurwicz (1952).

The *fourth example* (*4*) is related to the single-period spare parts quantity problem (SPQP) – an important element of the supply chain risk management (SCRM). SPQP is described for instance in Gaspars-Wieloch (2019c). The SPQP essence is to ensure that the right spare parts and resources are at the right place (where the broken part is) at the right time. The spare parts are kept in an inventory and should be in proximity to a functional item (machine, engine, device, etc.) because they might be used to repair it or to replace failed units. The SPQP objective is to determine the optimal number of service parts (q) bought with the purchase of the whole machine, i.e., to minimise the expected loss resulting from buying a given number of extra parts before potential breakdowns (i.e., risks). Buying too many parts with the whole device leads to a loss of money spent on the purchase of these parts, but buying not enough spare parts with the whole item causes a loss being the difference between the current price of a spare part and its previous price. We assume that company E has got historical data concerning the performance of all the former devices, so the demand (D) for extra parts can be described as a random variable with a known probability distribution. The company managers intend to use the selected strategy for 200 devices. Table 5 presents possible decisions (order quantities), scenarios (future demand) and losses $l(D,q)$ for different < demand, purchase > situations (from five to nine units). They are calculated on the basis of s_1 – the unit loss from buying a service part with the whole device (loss due to the excess of spare parts), and s_2 – the unit loss from buying an extra part just after the failure (loss due to the shortage of spare parts), see equation (1). These losses depend on two types of costs: c_1 signifies the unit purchase cost of the subassembly together with the purchase of the whole item and c_2 denotes the unit purchase cost of the subassembly just after the failure.

$$l(D,q)=\begin{cases} s_1(q-D), & if \quad q>D \\ 0, & if \quad q=D \\ s_2(D-q), & if \quad q<D \end{cases} \tag{1}$$

Table 5 Examples 4 and 5 – losses – fictitious data in thousands of euros, $c_1 = 3$, $c_2 = 13$, $s_1 = 3$, $s_2 = 10$

Probability	*Demand*	*Order quantity*				
		5	*6*	*7*	*8*	*9*
0,13	5	0	3	6	9	12
0,29	6	10	0	3	6	9
0,24	7	20	10	0	3	6
0,17	8	30	20	10	0	3
0,17	9	40	30	20	10	0

Source: Prepared by the author

Suggestions (example 4): in this example, thanks to the available equations and historical data, managers are able to:

1 define scenarios very precisely

2 assign probabilities of occurrence

3 evaluate the performance of strategic actions across the scenarios using the expected value

4 choose the action that is expected to perform best.

The decision is made here for 200 devices, thus, the probability is applied to repetitive events, which is theoretically allowed. The minimal expected loss is connected with q = 8 (e.g., eight boxes) and it equals 5.33 (thousands of euros). Nevertheless, it is worth mentioning that in many situations researchers recommend supporting the expected value with a second decision criterion, e.g., standard deviation (payoff dispersions) or distance between extreme values (Gaspars-Wieloch, 2017b).

The *fifth example* (*5*) concerns company F and also refers to the single-period SPQP and to the payoff matrix given in Table 5. The objective still consists in diminishing the risk impact, i.e., minimising the expected loss. It is assumed again that historical data are available and that the probability distribution can be determined, but this time the purchase is made only for one device. Such strategies are named one-shot decisions. In contradiction to multi-shots decisions, they are selected for just one execution (Guo, 2014).

Suggestions (example 5): although the problem is quite similar to the previous one, we do not recommend combining probabilities with SP since circumstances are fundamentally different – company F intends to buy the repair parts just for one machine, hence there are no repetitive events! Let us recall the von Mises (1949) statement: the probability of a single event should not be expressed numerically as probabilities only concern repetitive situations. Thus, even if the likelihood is easy to define thanks to the analysis of the performance of other analogous devices, it does not mean that we are obliged to make use of it. As a matter of fact, case IV is connected with the class probability while case V is related to the case probability (von Mises, 1949) and should not be associated with frequency. Perhaps the propensity probability theory would be appropriate here since it can be even applied to one-shot decisions, but it is only possible in the case of traditional products and services where the DM's knowledge about them is satisfactory.

Let us end this section with a multiple criteria RM problem (*example 6*). Bank G is analysing six alternatives differing from each other in terms of the level of the annual saving rates (from 1.5% to 6.5%). The bank intends to appraise particular strategies by taking three criteria into account:

1 financial bank liquidity

2 number of customers

3 annual bank profit.

For each option the experts have made an attempt to identify and assess possible threats. They have noticed that the impact of particular risks cannot be given as a deterministic parameter – their influence depends on diverse factors which have been investigated and categorised into five scenarios. Thus, the considered problem ought to be presented on the basis of three payoff matrices (separately for each target), and each matrix should contain five rows (for scenarios) and six columns (for alternatives). That means that

90 parameters are supposed to be estimated (three criteria × six decisions × five scenarios = 90 results).

Suggestions (example 6): we have certainly noticed that this problem is considerably more complex than the previous examples. Therefore, a teamwork for SP is here extremely desired, but is a team able to reach agreement on probabilities of occurrence? Let us recall that from the point of view of some practitioners 'the use of probabilities would compromise the team-building benefits'. Why is it so hard for the team to set a unanimous probability distribution? In Section 3 we have put emphasise on the fact that a universal probability definition does not exist. Hence, each member of the team may want to estimate the likelihood in a different way! Additionally, it is worth stressing that particular scenarios have been built on the basis of the analysis of numerous factors, which means that they are not constructed from the same underlying dimensions and they definitely do not constitute a complete probability space.

5 Conclusions

The paper is a continuation of two contributions (Hoffmann, 2017a; Millett, 2009) where the authors evaluate the usefulness of SP in RM and the suitability of probabilities in SP. In this work we try to verify whether it is worth combining SP with probabilities in a RM context, which is a specific case of uncertain decision-making. We make a review of standpoints found in the literature and also present our proper recommendations based on several illustrative RM examples.

Note that SP can be understood as a tool generating scenarios representing possible strategies (decisions) or as a method defining scenarios treated as possible situations. In this article we adopted the second approach and only that one was investigated.

The general conclusions are as follows:

1. SP is rather eagerly used by project managers since it is comfortable and allows one to analyse a given problem in a more deterministic way than for example fuzzy numbers or continuous probability distributions.
2. Probabilities may computationally improve the decision-making process, but they should not be combined with SP in many economic decision problems, especially related to RM.
3. We advise one against the assignment of probabilities to scenarios, if they are difficult to estimate due to the lack of experience and insufficient knowledge about a given RM problem. This is in particular the case of innovative and innovation products (projects).
4. Determining probabilities is the fundamental difficulty in risk assessment because the statistical information is not available on all kinds of past incidents (especially in the case of catastrophic events due to their infrequency). However, even if the DM has got access to historical data, he/she should not use them to compute probabilities if some new future factors, being able to radically change the trend up to now, are anticipated.

5 Probability estimations are redundant in the case of one-shot decision problems since only one scenario will have the chance to occur. In many real RM problems the DMs deal with non-repetitive events, so even if the probability distribution is available, it does not mean that it must be taken into account.

6 One-shot decisions can be associated with probabilities if they are set on the basis of the propensity theory and the knowledge about the problem is sufficient. Hence, when applying that approach, historical data are not required, but if a given decision problem is characterised by a very high novelty degree, even that probability definition will not be helpful.

7 The inconvenience connected with the combination of probabilities with SP may result from the lack of a universal and unanimous probability definition. This situation leads to numerous doubts in the DM's mind. He or she might not be able to choose a proper definition for a given problem. This phenomenon is especially disquieting in the case of teamwork scenario-based RM.

8 In connection with the fact that the use of probabilities in SP can be sometimes inadvisable, managers need alternative tools. Therefore, we recommend applying such measures as the coefficients of pessimism (optimism) in order to generate probability-like quantities. This approach allows one to take into consideration the DM's attitude towards risk.

9 In the literature many RM problems are theoretically regarded as 'stochastic problems' (with a known probability distribution) (Sikora, 2008) – this is for example the case of the spare parts quantity problem (Gaspars-Wieloch, 2019c), the newsvendor problem (Gaspars-Wieloch, 2017b) and securities portfolio optimisation (Gaspars-Wieloch, 2015c) – but we strongly encourage treating them as 'strategic problems' (with an unknown probability distribution), because in real circumstances managers often face insufficient knowledge and experience – markets are changing all the time (Guo, 2014).

10 All the guidelines formulated above have mainly practical implications which may be helpful for company and project managers (planners). As a matter of fact, they should not try to assign probabilities to each scenario in each case. The analysis of that issue from different points of view has revealed that in many RM situations the combination of SP with probabilities is incorrect and may lead to unreasonable decisions.

In the future research, it would be desirable to explore the topic discussed in the paper in the context of alternative tools (i.e., other than probabilities) supporting SP in RM. It will certainly lead to new interesting observations.

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