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ENHANCING SCENARIO TECHNIQUE BY TIME-VARIANT IMPACTS

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1. Introduction

For the design of promising products it is of fundamental importance to anticipate potential future development. Future development may include consumer needs, market trends or technological development. Scenario technique is used for anticipating potential future development in the context of strategic management [Reibnitz 1992], [Götze 1993], [Gausemeier and Plass 2014], deriving future societal or environmental scenarios [Godet 1994], [Arcade et al. 1999] and for product development itself [Paul 1996], [Randt 2015]. During product development scenario technique is applied for anticipation of potential technological development trends and identification of future market demands. The scenario technique can support identification of potentials for a market pull or a technology push for the development of successive products to turn inventions into economic success to generate welfare. Within this paper, an approach with time-variant impacts in the impact matrix is presented. This approach enables the consideration of time-dependencies as well as time lags in the selection of the key influence factors for consistency analysis of the scenario technique. Thereby precision and transparency of the scenario technique are improved. The state of the art of the scenario technique is presented in section 2. Section 3 is focused on the time-variant impacts. In section 3.1. different impact effect functions (IEFs) are developed. The required cross-impact matrices are presented in section 3.2. A time-dependent system grid is outlined in section 3.3. The approach is applied to a practical example in section 4. Section 5 concludes with a discussion of the results and an outlook on future research.

2. State of the art and related work

2.1 Scenario technique

Originating from the initial scenario technique developed by the Stanford research institute [Bishop et al. 2007], different methods for the anticipation of scenarios have been developed [Meyer-Schönherr 1992].

The cross-impact analysis was originally developed by Gordon and Hayward [1968]. Within the cross-impact analysis, the probability values of certain influence factors and their possible development are adapted according to the occurrence of one development trend of a specific influence factor. The cross-impact matrix indicates the strength and the direction of a possible cross-impact of the occurrence of one influence factor's development trend on the probability of the occurrence of another. Based on the cross-impact analysis, various approaches for the calculation of conditional probabilities have been developed [Enzer 1980a,b], [Honton et al. 1984]. Based on the cross-impact analysis, Godet developed a method ("MICMAC") to identify indirect impacts within the cross-impact matrix by the multiplication of these [Godet 1987, 1994], [Arcade et al. 1999]. Other approaches imply different algorithms to identify indirect impacts [Villacorta et al. 2011]. Indirect impacts are important for the identification of variables or influence factors, which exert a major influence on the system by indirect impacts or loops [Godet 1994]. During recent years, the cross-impact analysis has been advanced by the implementation of fuzzy numbers within the cross-impact matrix [Jeong and Kim 1997], [Asan et al. 2004]. These approaches also include the analysis of indirect impacts within the fuzzy linguistic MICMAC (FLMICMAC) method [Villacorta et al. 2014].

Besides the cross-impact analysis, the consistency analysis is another approach towards the scenario technique. In consistency analysis, scenarios are not only derived on the basis of the cross-impact matrices but also on the consistency matrix. Originally developed by Reibnitz [1992], this method is particularly popular and applied in Europe. On basis of consistency analysis, various process models been have evolved [Gausemeier 1995], [Götze 2013], [Gausemeier and Plass 2014]. Among consistency analysis-based methods, both impact as well as consistency matrices can be found. The impact matrices represent - in analogy to the cross-impact matrices - the direct influences between the influence factors. Here, only the impacts of the influence factors onto each other are considered, while the interdependencies of the development of the influence factors remain unconsidered. Within the impact matrix, feedback loops or indirect influences may be assessed by the MICMAC method or by graph theoretical approaches such as the qualitative input output analysis [Mißler-Behr 1993]. In a next step of the method, key influence factors are identified. This process is described in detail in section 2.3 of this paper. After the identification of the key influence factors, consistency of possible development trends of these key influence factors are assessed in the consistency matrix [Reibnitz 1992]. The values within the consistency matrix represent possible consistencies on a scale between total inconsistency and total consistency. Based on the consistency matrix, scenarios are developed. Criteria for aggregating development trends of key influence factors to a scenario are: consistency, difference and stability [Reibnitz 1992], [Mißler-Behr 1993]. Scenarios are derived by applying different optimization algorithms. These include linear optimization, branch-and-bound [Nitzsch et al. 1985] or evolutionary algorithms [Hofmeister 2000], [Grienitz and Schmidt 2009]. In consistency-based methods, fuzzy numbers are used either for the assessment of consistencies within the consistency matrices [Mißler-Behr 2001], [Kratzberg 2009] or in the context of clustering process for the scenario derivation [Hofmeister et al. 2000]. Neuronal networks may be used for the set-up of the consistency matrix [Dönitz 2009].

2.2 Time-dependency in the cross-impact matrix for cross-impact analysis

The idea of adding time-dependent impacts in the cross-impact matrix was already outlined by Gordon and Hayward in [1968]. The approach proposed by Gordon and Hayward is focused on the time lag between the occurrence of an event and its impact on the probability of occurrence of other impact factors [Gordon and Hayward 1968]. Other authors investigate the effect of the sequence of events on the estimation of probabilities within the cross-impact analysis [Serdar Asan and Asan 2007]. Fuzzy numbers may also be used to analyse the time delay between the occurrence of realizations of impact factors [Jeong and Kim 1997]. The probabilities within the cross-impact analysis may also be considered as time-dependent functions [Bloom 1977]. Asan et al. proposed an approach in which the cross-impact matrix is combined with a time matrix incorporating possible time delays (cross-impact analysis with time consideration (CIAT)) [Serdar Asan and Asan 2007]. The assessment of impacts is based on a shortest path algorithm, the Floyd-Warshall algorithm [Ahuja et al. 1993], [Serdar Asan and Asan 2007]. The application of the CIAT approach may differ - in case of indirect influences - from the MICMAC approach proposed by Godet [Serdar Asan and Asan 2007].

In the context of consistency analysis, time-variant impacts have not yet been considered. Impacts for the selection of key influence factors are only considered as time-invariant. The consideration of time-variant impacts can enhance the precision of the selection of key influence factors. Thereby the quality of the resulting scenarios is improved.

2.3 Selection of key influence factors

In order to make the effort for setup of consistency analysis manageable, the key influence factors have to be identified. Key influence factors are a selected subset of the set of all influence factors. Reibnitz proposes a system grid (Figure 1) in which influence factors are sorted by their active sum (AS; considering direct impacts exerted onto others by this factor) and their passive sum (PS; considering the impact of other factors onto this factor) [Reibnitz 1992]. Within the system grid, the average AS and PS mark the boundaries of the fields for the influence factors as described in Figure 1. Reibnitz considers active and ambivalent elements as more important than passive elements. Non-ambivalent elements are of least importance for the system behaviour.

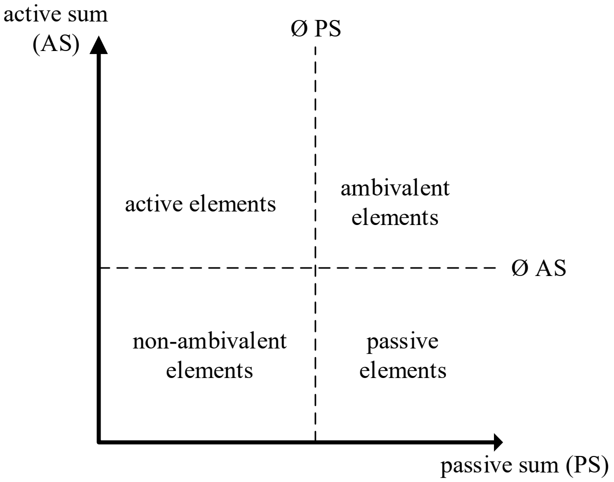


Figure 1. System-grid according to Reibnitz [1992]

Gausemeier applies the active as well as the passive sum in combination with the dynamic index (DI, multiplication of AS and PS) and the impulse index (IPI, quotient of AS and PS) [Gausemeier 1995], [Gausemeier and Plass 2014]. The application of the DI can be found in various approaches [Mißler-Behr 1993, 2001], [Götze 2006, 2013], [Serdar Asan and Asan 2007]. Gausemeier applies an advanced version of the system grid to identify the key influence factors [Gausemeier et al. 1996]. All approaches can be combined with the MICMAC method to identify indirect impacts. To select the influence factors, various selection rules may be applied. While the selection rules are not dependent on the purpose of the scenario within the system grid [Reibnitz 1992], Gausemeier differentiates the purpose and the scope (time horizon) of the scenarios for the selection [Gausemeier 1995]. Influence factors are either sorted by AS, PS or DI and IPI dependent on the purpose and the scope of the scenario project.

3. Time-variance in the impact matrix for consistency analysis

Within consistency analysis the identification of key influence factors for different scopes of the scenario project is based on either AS and PS [Reibnitz 1992] which can be combined with IPI or DI [Gausemeier and Plass 2014]. The heuristic selection of influence factors lacks transparency and the precision is highly dependent on the expertise of the user of scenario technique. Time-variant impacts are not implemented in the heuristic selection of influence factors in consistency analysis.

An impact matrix with time dependencies will improve the identification of key influence factors for the derivation of scenarios in multiple ways:

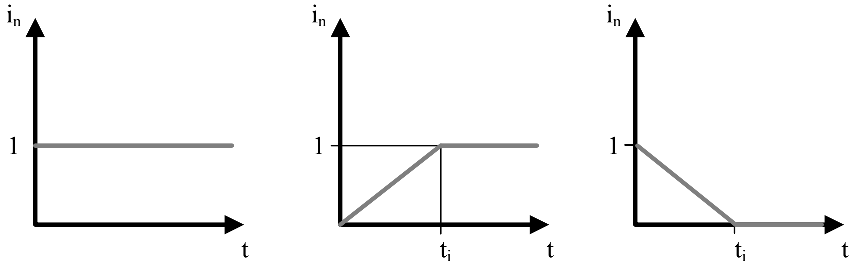
- The time lag between the realization of one influence factor and the realization of other impact factors can be considered. A direct impact on another influence factor will possibly not exert any influence for the scenario development if the time scope of the scenario is rather short-term and the time lag rather long. In that case, the impact shall possibly not exert any influence on the resulting scenario.
- The indirect impact with a short time lag may possibly dominate a direct impact with a longer time lag. This time-dependent exertion of impacts is not covered the recent approaches.
- Time-dependent feedback loops have to be considered in dependency on time scope of the scenario analysis.

In order to improve scenario technique, especially the identification of key influence factors for the consistency analysis, an approach based on time dependent impact effect functions is proposed in this paper.

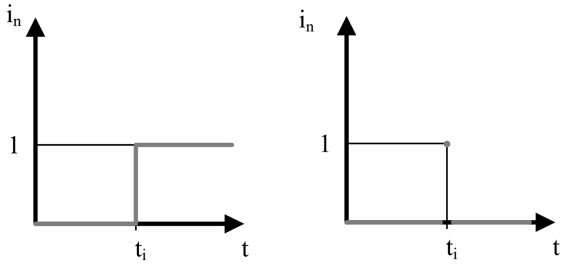
3.1 Impact effect functions

In order to incorporate time dependency of influence factors in the impact matrix, impact effect functions (IEF) have been developed and are proposed in the following. IEFs are characterized by two parameters:

- impact time t_i: the point of time when the impact reaches its highest value,
- shape: IEFs may appear in multiple shapes characterized below (Figure 2).



(a) constant IEF (b) linear progressing IEF (c) linear degressing IEF



(d) delayed IEF (e) single impact IEF

Figure 2. Impact effect functions

All IEFs are normalized. The highest possible normalized impact value i_n exerted is 1. When the strength or the direction of impacts may be considered - for instance on a scale between 0 and 2 proposed by Reibnitz [1992] - the IEFs may be multiplied (scaled) by the scale n given in the impact matrix.

The different IEFs can occur in various shapes. Within this paper, five different shapes are distinguished:

- constant IEF (con): The impact remains constant in course of time. This IEF represents a case similar to the cross-impact matrix without time consideration (Figure 2 (a)).

$$i_{con} = n * 1 \qquad \forall\, t \tag{1}$$

- linear progressing IEF (pro): The impact is exerted in a linear relation. Once the impact time t_i is reached, the influence remains constant with a normalized impact value of 1 (Figure 2 (b)).

$$i_{pro} = \begin{cases} n * 1 * \frac{t}{t_i} & t \leq t_i \\ n * 1 & t > t_i \end{cases} \tag{2}$$

- linear degressing IEF (deg): The impact is exerted in a linear relation. Starting with a normalized impact value of 1, the impact decreases till the value of 0 is reached within impact time t_i (Figure 2 (c)).

$$i_{deg} = \begin{cases} n * 1 * \left(1 - \frac{t}{t_i}\right) & t \leq t_i \\ 0 & t > t_i \end{cases} \tag{3}$$

- delayed impact IEF (del): The impact value remains 0 until the impact time t_i is reached. The normalized impact value steps up to the value of 1 and remains on a constant level. This implements a time lag in the exertion of impacts (Figure 2 (d)).

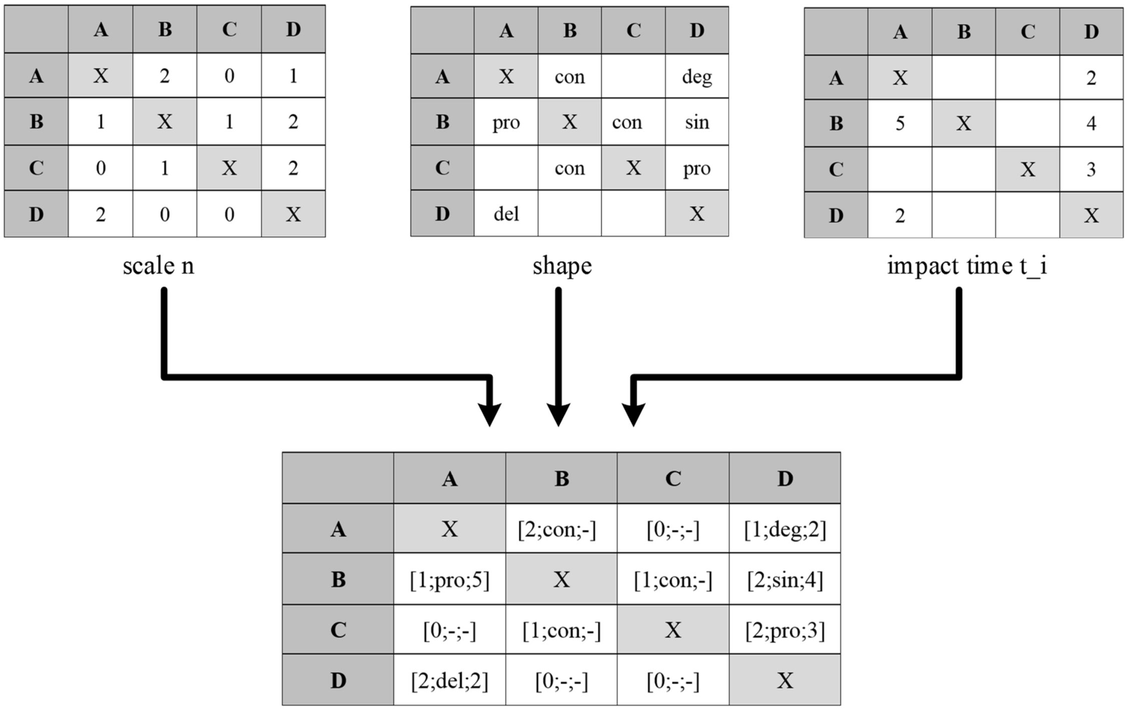
$$i_{del} = \begin{cases} 0 & t < t_i \\ n * 1 & t \geq t_i \end{cases} \tag{4}$$

- singular impact IEF (sin): Incorporating a singular impact. Once the impact time t_i is reached, the normalized impact value steps from 0 to 1. After impact time, the value drops down to 0 again (Figure 2 (e)).

$$i_{sin} = \begin{cases} 0 & t \neq t_i \\ n * 1 & t = t_i \end{cases} \tag{5}$$

3.2 Time-variant impact matrix

Implementation of the proposed IEFs for cross-impact analysis requires further information within the impact matrix. In addition to the impact value (scale n) itself, the matrix has to contain information on the shape of the IEF and its impact time t_i. This information is represented in two additional matrices. These additional matrices may be combined to an integrated impact matrix containing all information. In this matrix, cell elements contain vectors with the elements scaling factor n, shape and impact time t_i ([n; shape; t_i]). The three matrices and the resulting integrated impact matrix are shown in Figure 3.



	A	B	C	D
A	X	2	0	1
B	1	X	1	2
C	0	1	X	2
D	2	0	0	X

scale n

	A	B	C	D
A	X	con		deg
B	pro	X	con	sin
C		con	X	pro
D	del			X

shape

	A	B	C	D
A	X			2
B	5	X		4
C			X	3
D	2			X

impact time t_i

	A	B	C	D
A	X	[2;con;-]	[0;-;-]	[1;deg;2]
B	[1;pro;5]	X	[1;con;-]	[2;sin;4]
C	[0;-;-]	[1;con;-]	X	[2;pro;3]
D	[2;del;2]	[0;-;-]	[0;-;-]	X

Figure 3. Time-variant impact matrix

3.3 Selection of key influence factors

When implementing a time dependency in impact analysis of scenario technique, the key influence factors can not only be selected on basis of either direct or indirect impacts. Furthermore, the method for selecting key influence factors must incorporate time dependency as well. In this context, the scope of a scenario project is important. Direct and indirect impacts only have to be considered when impact time of these impacts (or even feedback loops) is shorter than the scope of the scenario project. Other impacts do not have to be taken into consideration for the identification of the influence factors. Selection of key influence factors includes the following steps:

1. Ranking of influence factors due to direct impacts
2. Considering time dependency in a time-variant AS as well as a time -variant PS
3. Identification of indirect impacts
4. Selection of key influence factors due to both, direct and indirect impacts using the system grid considering the scope of the scenario

Table 1 shows the resulting AS and PS for the generic example presented in section 3.2. Here t_0 represents a scope of 0 (time units (e.g. years)), t_1 a scope of 2 (time units (e.g. years)) and t_2 a scope of 4 (time units (e.g. years)).

Table 1. Active sum (AS) and passive sum (PS) for the generic example at various scopes

		scope					
		t_0		t_1		t_2	
		AS	PS	AS	PS	AS	PS
influence factors	A	3	0	2	2.4	2	2.8
	B	1	3	1.4	3	3.8	3
	C	1	1	1.6	1	3	1
	D	0	1	2	1.6	2	4
	Ø	1.25	1.25	1.75	1.75	2.7	2.7

The system grid for the generic example presented in section 3.2 is plotted in Figure 4. The time-dependent trajectory is marked for each influence factor. When investigating the initial state (t_0) influence factor A has the highest AS. Reibnitz considers A as an active influence factor [Reibnitz 1992]. B has a clear dominance of PS over AS and is therefore considered a passive element in the system-grid. Influence factor C serves as an element of low ambivality with a buffering role according to Reibnitz [1992]. Influence factor D lies in the field of active system elements.

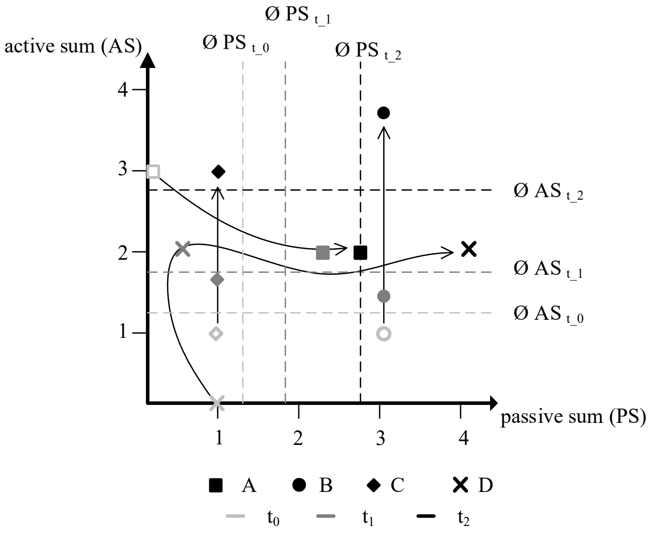


Figure 4. Time-dependent system grid with trajectory of influence variables

As depicted in Figure 4, the position of the influence factors is time-variant. The time-dependent positions at scopes of t_0, t_1 and t_2 resembles a trajectory of the different influence factors. Influence factor A moves from the active to the passive elements. The AS of B and C is increasing with a longer scope, moving these elements into area of ambivalent or active system elements. The boundaries between the classes of system elements are time-dependent as well. When influence factors are sorted in analogy to Reibnitz the resulting sequence is:

- for the scope of t_0: A - B - D - C
- for the scope of t_1: A - D - B - C
- for the scope of t_2: B - C - D -A

For a longer scope of scenarios, the impact of influence factors B and C is more important and dominates the impact of influence factor A. Dependent on the desired scope of a scenario, different influence factors have to be selected as key influence factors.

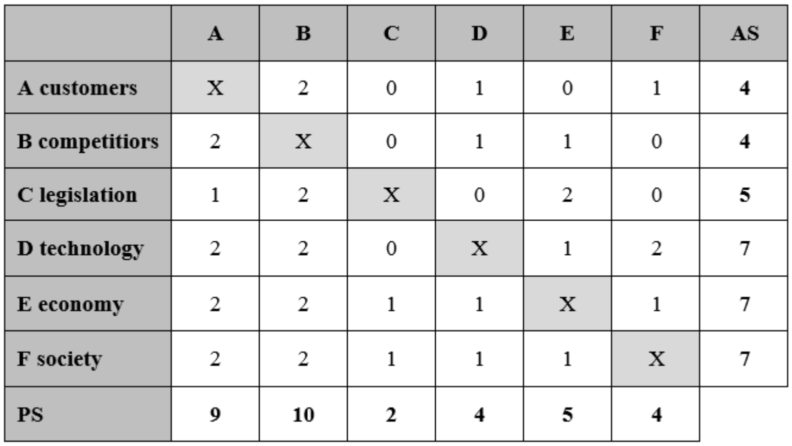
When indirect impacts or possible loops are considered, the length of the impact paths and the possible delay (in the time domain) have to be considered. Given the generic example from section 3.2 with integrated impact matrix presented in Figure 3, the following indirect impacts or loops can be discovered:

- indirect impact B → C → D with a time delay of 3 (time units)
- indirect impact C → D → A with a time delay of 3 (time units)
- indirect impact B → C → D → A with a time delay of 5 (time units)
- closed feedback loop A → B → A with a time delay of 5 (time units)
- closed feedback loop A → B → C → D → A with a time delay of 5 (time units)

Dependent on the scope of the scenario project, the indirect influences can possibly affect the selection of key influence factors. For the scopes of t_0 and t_1; none of the feedback loops or indirect impacts presented will influence the system due to the time delays. Only at a scope of t_2; the first two indirect impacts will have an influence on the resulting scenarios. Therefore, these indirect impacts must be considered in the selection of the key influence factors.

4. Application "Bank of the future"

As application scenario of time-variant impacts in the consistency analysis a given scenario project "Bank of the future" presented by Reibnitz [1992] and used as an application scenario by Missler-Behr [1993, 2001] is selected. The purpose is to develop scenarios for the future development of a retail bank. On this basis, the above described time-variant impact presented in section 3 is illustrated and verified. The scenario project consisted of 6 influence factors: customers, competitors, legislation, technology, economy and society. The initial impact matrix is shown in Figure 5.



	A	B	C	D	E	F	AS
A customers	X	2	0	1	0	1	**4**
B competitiors	2	X	0	1	1	0	**4**
C legislation	1	2	X	0	2	0	**5**
D technology	2	2	0	X	1	2	**7**
E economy	2	2	1	1	X	1	**7**
F society	2	2	1	1	1	X	**7**
PS	**9**	**10**	**2**	**4**	**5**	**4**	

Figure 5. Impact matrix for the "Bank of the future" without IEFs

When plotted into a system grid, the influence factors D and F as well as E are considered the most important. Customers (A) and competitors (B) are passive influence factors for the system. The scope of the scenario project is relatively short (maximum 8 years). Dependent on the scope of the scenario planning, the influence factors A and B will have a stronger influence on the potential future scenarios with a shorter scope. IEFs were applied to the cross-impact matrix shown in Figure 8. The results are given as an integrated impact matrix in Figure 6.

	A	B	C	D	E	F	$AS_{t=0}$ [years]	$AS_{t=4}$ [years]
A customers	X	[2; con; -]	[0; -; -]	[1; con; -]	[0; -; -]	[1; del; 4]	**3**	**4**
B competitiors	[2; con; -]	X	[0; -; -]	[1; con; -]	[1; con; -]	[0; -; -]	**4**	**4**
C legislation	[1; con; -]	[2; del; 1]	X	[0; -; -]	[2; del, 2]	[0; -; -]	**1**	**5**
D technology	[2; pro; 2]	[2; con; -]	[0; -; -]	X	[1; del; 4]	[2, del; 2]	**2**	**7**
E economy	[2; con; .]	[2; con; -]	[1; del; 4]	[1; pro; 2]	X	[1; pro, 2]	**4**	**7**
F society	[2; pro; 4]	[2; pro; 4]	[1; pro; 2]	[1; del; 4]	[1; del, 4]	X	**0**	**7**
$PS_{t=0}$ [years]	**5**	**6**	**0**	**2**	**1**	**0**		
$PS_{t=4}$ [years]	**9**	**10**	**2**	**4**	**5**	**4**		

Figure 6. Integrated impact matrix containing the IEFs for the "Bank of the future"

The impact values remain unchanged to the initial data set. The impacts of influence factors such as legislation, technology, economy or society on each other are characterized by either delayed or progressing IEFs to depict the actual speed of adaptation or technologic diffusion. When the time variant impacts are considered, the AS and PS for a longer scenario scope (t ≥ 4 [years]) remain unchanged compared to the initial example without the implementation of IEFs. The average AS and PS values are 4.5 and 5.7. Once a shorter scope is investigated, the average AS and PS values decrease to 2 for both average AS and PS. When the time-dependent system grid is considered, the influence factors which were considered less important in the longer time-scope are characterized by the highest AS and PS. Compared to the average values marking the areas in the system grid, the influence factors A and B are now in the field of ambivalent system elements which exert a major impact on the system, while the influence factors C, D and F are characterized as system elements with a minor influence on the system since their AS and PS are smaller than the average values. The time-dependent system grid for the "Bank of the future" is shown in Figure 7.

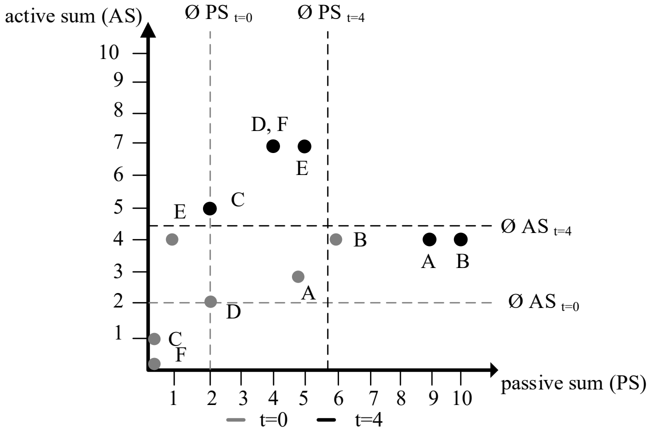


Figure 7. Time-dependent system grid for the "Bank of the future"

For a short scope, the key influence factors selected on basis of the initial impact matrix differ from the selection founded on the time-variant impact matrix. Instead of influence factors D, E and F, the influence factors A, B and E have an increased impact on the system for a shorter scope. The influence factors customers (A) and competitors (B) are taken as key influence factors for the scenario derivation. The presented application shows the advantages of the presented approach: By applying IEFs, the selection of the key influence factors is time-dependent. The selection is not only based on heuristic approaches or the experience of the user of the scenario technique. Transparency and traceability of the resulting scenarios thus increases. Thereby, the acceptance of the results increases as well.

5. Conclusion, evaluation and outlook

Within this paper, an approach to implement time-variant impacts within the impact matrix was presented. Hereby, time-variant impacts can be implemented in the consistency analysis. The approach is based on impact effect functions (IEFs) which are characterized by the parameters shape and impact time. The application of IEFs enables the depiction of time variant-impacts for the impact analysis of scenario technique. Selection of key influence factors is based on a time-dependent system grid. The differences between the IEF-approach and existing consistency analysis is shown in Figure 8.

	existing consistency analysis [Reibnitz 1992, Gausemeier and Plass 2014; Gausemeier 1995; Götze 2013]	**consistency analysis with implemented IEFs**
influences	• time-static influences • characterized by impact value ("scale")	• time-variant influences • implementation of normalized IEFs • characterized by parameters scale n, impact time t_i and shape
impact matrix	• containing information about the impact value ("scale")	• integrated impact matrix • information about scale n, impact time t_i and shape
selection of key influence factors	• based on the system grid • based on AS, PS, IPI and DI	• time-dependent system grid • position of influence factors is time-variant • trajectory of influence factors • selection is dependent on scope of the scenario project

Figure 8. Differences between existing consistency analysis and consistency analysis with implemented IEFs

Precision and transparency of scenario technique is improved by the presented approach of time-variant impact. The selection of key influence factors relevant for the development of the scenarios is not only based on the direct and indirect impacts, but also founded on the consideration of a time sequence or time variant development of these impacts. This facilitates the correct selection of key influence factors, since the potential influence on the influence factors on the system is depicted in the system grid. Other approaches used for the selection of key influence factors often depend on the intuition of the user of scenario technique in case of the key influence factor selection. Using IEFs, the selection process is made more precise and transparent, improving the acceptance and traceability of the results. This way improved scenario technique enables a better fit to market for future product development by the possibility to anticipate potential future market demands (market pull) or the most successful point of time for a technology push. Thereby the change process from an invention into an innovation creating economic success and welfare can be anticipated and the success rate of new product development is improved.

Future work will focus on enhancement of the approaches towards the detection of indirect impacts. The MICMAC-approach, based on multiplication of impact matrices, is not suitable for the application of the IEF-approach. Application of the Floyd-Warshall algorithm for the identification of the shortest time paths within the impact matrix has to be investigated. New identification algorithms for the indirect impacts considering time scope of the scenario project have to be developed. These will be in focus of future work. Further enhancements will be implementation of further types of IEFs. Identification of these is of fundamental importance for the quality of the scenario analysis. The automatization of the detection of IEFs will also be part of future research.

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