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ABSTRACT: This paper introduces an extended formulation of decision analyses, which provides an enhanced basis for the definition of the value of information, the value of actions and the value of actions and information analyses. The formulation of decision analyses is (1) extended by introducing an action implementation uncertainty and - following the reasoning of Raiffa and Schlaifer (1961) - (2) by considering both the information acquirement state and the action implementation state jointly and separately for the definition of the types of decision analyses. Decision value analyses are derived by explicitly distinguishing and addressing the cause of the expected utility gain namely by information, by actions or by both action and information. It is shown how different optimal sets of information and actions and their acquirement or implementations states, respectively, lead to different decision value classifications. Published studies and applied decision and decision value analyses are analyzed showing a diversity beyond the original definitions by Raiffa and Schlaifer (1961), however, also being less diverse in comparison to the introduced classification in this paper.

1. INTRODUCTION

The value of information is defined as the expected utility gain by obtained (conditional) or predicted (expected) information including their costs and consequences (according to Raiffa and Schlaifer (1961) with the difference of the costs and consequences of the information). The expected utility gain is defined as the difference between a pre-posterior (for predicted) or a posterior decision analysis (for obtained information) and a prior decision analysis. These definitions imply that the information acquirement states (predicted, obtained, not considered) defines the decision analysis and thus the value of information analysis types. However, it is observed that first the physical actions and measures, which are essential for enforcing the functionality of a system, do not contribute to the classification of the decision analyses and second that action implementation uncertainties are not considered (Thöns (2018a)). Both shortcomings prevent a consistent modelling by unbalanced modelling detailing despite the fact that action implementation uncertainty models can be found in the literature (Section 5). It is further noted that decision analysis does address the fundamental decision of at all obtaining any information and to implement any action.

With this paper it is thus tried to introduce a consistent formulation of decision analysis by (1) the consideration of both the information acquirement and action implementation states, (2) by the consideration of the action implementation uncertainty and (3) by the consideration of the a system state analysis to decide about the fundamental efficiency of any additional information and action. In Section 2, the current decision and value of information analyses understanding is summarized. The extended definition of decision analysis with formulations on how to quantify the expected utilities are introduced in Section 3. Building upon the extended definition of decision analyses, decision value analysis types with a base and enhancement scenario are derived (Section 4) and consecutively formulated to quantify the value of predicted and obtained information, the value of predicted and implemented actions and the value of information and actions. Section 5 contains a summary and analysis of applied decision and decision value analyses in respect to the introduced framework.

2. DECISION ANALYSIS AND VALUE OF INFORMATION

Decision theory in Raiffa and Schlaifer (1961), its introduction to civil engineering (Benjamin and Cornell (1970)) and recent interpretation in engineering e.g. with Faber and Thöns (2013), Straub (2014), Memarzadeh and Pozzi (2016), Straub, Chatzi et al. (2017) and Thöns (2018b) is based upon the distinction of prior, posterior and pre-posterior decision analysis types (depicted in Figure 1) and the corresponding value of information analysis types namely the conditional or expected value of perfect or sample information (CPVI, CPSI, EVPI and EVSI). It is further noted that reviews across the scientific fields address these types of value of information analyses – sometimes with a slightly different notation and refined models (see e.g. Keisler, Collier et al. (2014), Yokota and Thompson (2004)).

A value of information analysis addresses (1) the fundamental decision of considering additional and yet unknown information or not, (2) the identification of an optimal risk and integrity management strategy, (3) the identification of optimal actions with and without (4) additional information.

The fundamental decision of considering additional and yet unknown information or not can be based upon a positive and maximized value of information V. The maximization of the value of information is calculated maximizing the difference between the expected utilities with and without additional information, $U_1\left(i_i^*,\mathbf{a}^{*,i}\right)$ and $U_0\left(a_k^{*,0}\right)$ (Equ.(1)), respectively, by identifying the optimal strategy i_i^*, the information outcomes dependent optimal set of actions $\mathbf{a}^{*,i}$ and the optimal actions without additional information, $a_k^{*,0}$.

$$
\begin{aligned}
V\left(i_i^*\right) &= U_1\left(i_i^*,\mathbf{a}_{i_i^*}^*\right) - U_0\left(a_k^{*,0}\right) \\
&= \max_{i_i\in\mathbf{i},\mathbf{a}_{i_i}\in\mathbf{a}} U_1\left(i_i,\mathbf{a}_{i_i}\right) - \max_{a_{k,0}\in\mathbf{a}} U_0\left(a_{k,0}\right)
\end{aligned}
\tag{1}
$$

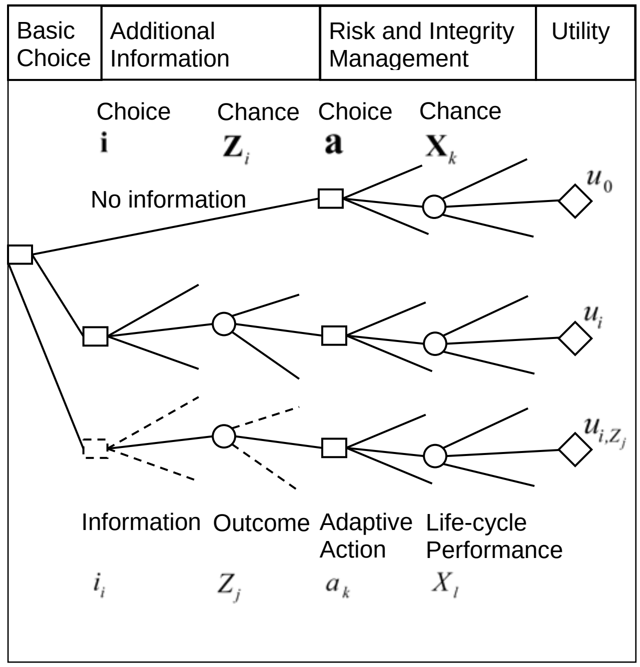

Figure 1: Decision tree for the assessment of the (conditional) value of information containing decision nodes (rectangles), chance nodes (circles) and utility nodes (diamonds). The dashed lines denote not considered information and outcomes in a posterior type decision analysis.

3. EXTENDED DECISION ANALYSIS

Decision analyses are understood as addressing, modelling, analyzing and optimizing the knowledge and performance management of the infrastructure system utilities (Thöns (2018a)). The extended classification of decision analyses – by definition with at least one decision node - is shown in Figure 2. The index i is introduced to allocate both actions and information to one knowledge and performance management strategy. The individual types of decision analyses are derived based on the acquirement state of information and the implementation state of actions. An additional chance node accounting for the action implementation uncertainty is introduced. Not yet implemented decisions are depicted with continuous lines; already implemented decision are shown with one continuous line and dashed lines are used for the not implemented decisions. A system state analysis (SSA) is introduced to address the fundamental decision whether at all to implement any information acquirement and actions strategies.

The expected utility for an information and action predictive decision analysis (PIPA) can be derived in a normal form with the consecutive conditional expectation operations: The expectation of the information outcomes given the system and action implementation states $E_{Z_{i,k}|Y_{i,m},X_n}[\ldots]$, the expectation of the action implementation state given the system state $E_{Y_{i,m}|X_n}[\ldots]$ and the expectation of the system states $E_{X_n}[\ldots]$ (Equ. (6)). With the maximization of the utilities, the optimal information acquirement strategy i_i^* and the indication dependent optimal set of actions $\mathbf{a}_i^*$ can be identified.

$$U^*_{PIPA}\left(i_i^*,\mathbf{a}_i^*\right) = \max_{i_{i,j}\in\mathbf{i}_i,\mathbf{a}_i^*\in\mathbf{a}_i} E_{X_n}\left[E_{Y_{i,m}|X_n}\left[E_{Z_{i,k}|Y_{i,m},X_n}\left[U\left(\ldots\right)\right]\right]\right] \quad (2)$$

For the calculation of the expected utility for already obtained information (OI: (i_i, Z_i)) but predicted actions (PA), the expectation in regard to expectation of the information outcomes given the system and action implementation states can be neglected to identify the optimal action a_i^* of knowledge and performance management strategy i:

$$U^*_{OIPA}\left(a_i^*\right) = \max_{a_{i,l}} E_{X_n}\left[E_{Y_{i,m}|X_n}\left[U\left(i_i,Z_i,a_{i,l},Y_{i,m},X_n\right)\right]\right] \quad (3)$$

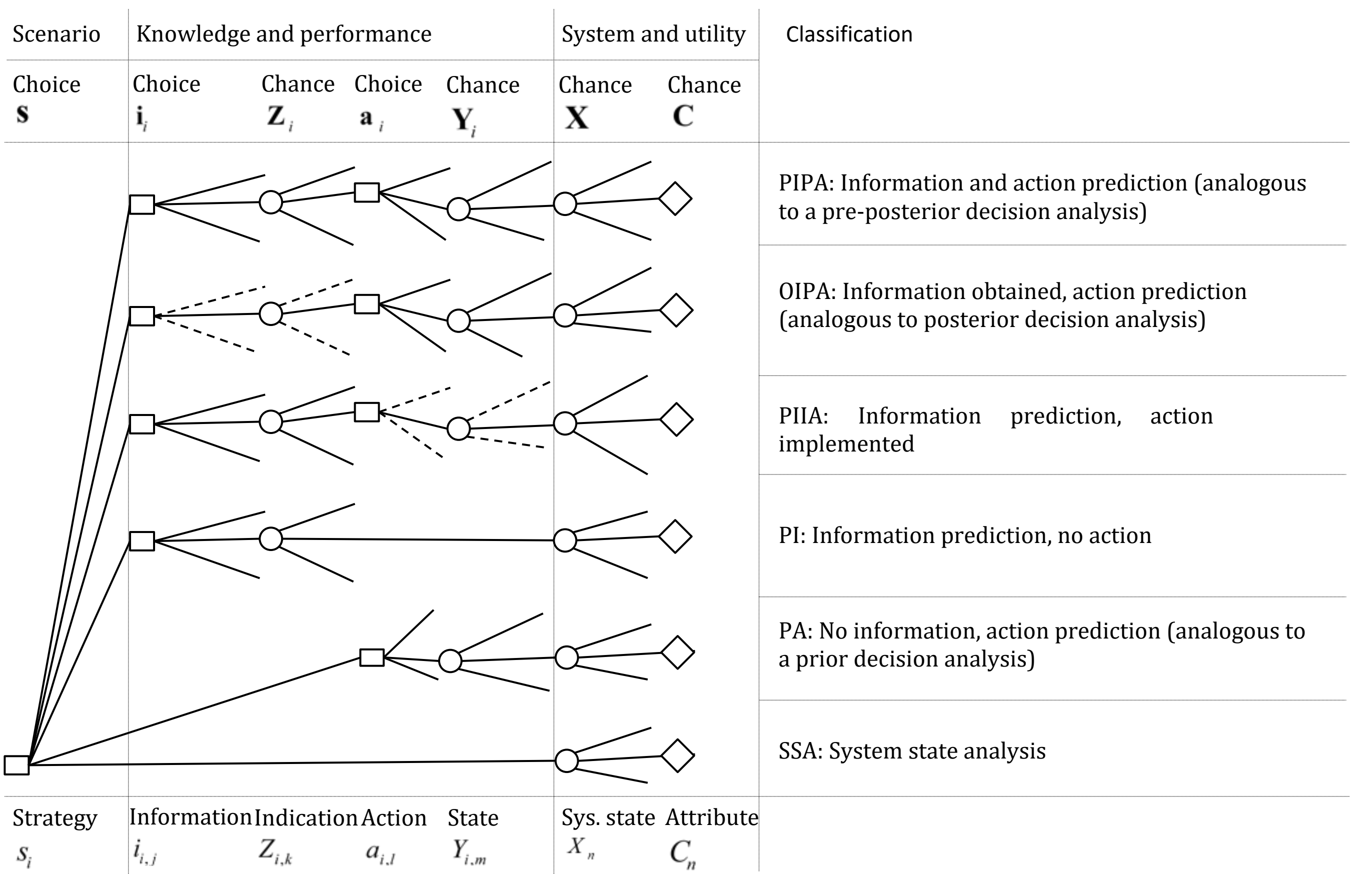

Figure 2: Illustration of the extended classification of decision analyses with decision trees

A decision analysis with predicted (pre-posterior) information (PI) and already implemented actions (IA: $\left(a_i, Y_i\right)$) aims at the identification of the optimal information acquirement strategy to maximize the expected utility. The expected utility is calculated with the expectation and maximization in regard to the information outcomes given the system and action implementation states and in regard to the system states:

$$U_{PIIA}^{*}\left(i_i^{*}\right) = \max_{i_{i,j}} E_{X_n}\left[E_{Z_{i,k}|Y_i,X_n}\left[U\left(i_{i,j}, Z_{i,k}, a_i, Y_i, X_n\right)\right]\right] \quad (4)$$

Decision analyses solely about information acquirement (PI) or action implementation (PA) aim at an uncertainty reduction in respect to the behaviour of the real world system and at the implementation of performance enforcing measures, respectively. Two expectation operations are required due to the involvement of two chance nodes. It should be noted that the expected utility for a PI analysis with indication-independent utility attributes equals a system state analysis plus the expected information acquirement costs leading to obsolete decisions. Thus, a PI analysis is only valid for indication-dependent utility attributes.

$$U_{PI}^{*}\left(i_{i,j^*}\right) = \max_{i_{i,j}} E_{X_n}\left[E_{Z_{i,k}|X_n}\left[U\left(i_{i,j}, Z_{i,k}, X_n\right)\right]\right] \quad (5)$$

$$U_{PA}^{*}\left(a_i^{*}\right) = \max_{a_{i,l}} E_{X_n}\left[E_{Y_{i,m}|X_n}\left[U\left(a_{i,l}, Y_{i,m}, X_n\right)\right]\right] \quad (6)$$

The expected utility without any information or actions is quantified with a system state analysis for which a risk analysis constitutes a special case when only consequences are considered.

$$U_{SSA} = E_{X_n}\left[U\left(X_n\right)\right] \quad (7)$$

A system state analysis is necessitated by the fact that any action and information should be relevant and efficiently implemented or obtained. This means that e.g. for any non-acceptable risk (relevance) any risk reduction measure or information should only be spent when the expected costs are overcompensated by the risk reduction (efficiency).

4. VALUE OF DECISIONS

The value of decisions is quantified as an expected utility gain by a predicted or an implemented decision. The quantification of an expected utility gain implies two decision scenarios following the introduced classification (Section 3).

For a decision value analysis, a base scenario and an enhancement scenario are required. The decision value is denoted as $V_{Base}^{Enhancement}$. By systematically allocating all combinations of decision analysis classes (Figure 2), 20 types of decision value analysis types can be derived (Figure 3).

The difference in the base and enhancement decision scenarios defines the type of decision value analysis. It is distinguished between (1) a value of information, (2) a value of actions and (3) a value of information and action analysis. In a value of information analysis, the expected utility gain is solely caused by predicted or already obtained information (see Sections 1 and 2). Analogous, the decision value of actions is solely caused by predicted or already implemented actions. An expected utility gain by both information and actions – regardless of their acquirement or implementation state – is termed as value of information action analysis. Value of a decision may also involve the comparison between two set of actions (value of actions) and/or two sets of information (value of information). It should be noted that not the entire combinations list in Figure 3 fit into the classification.

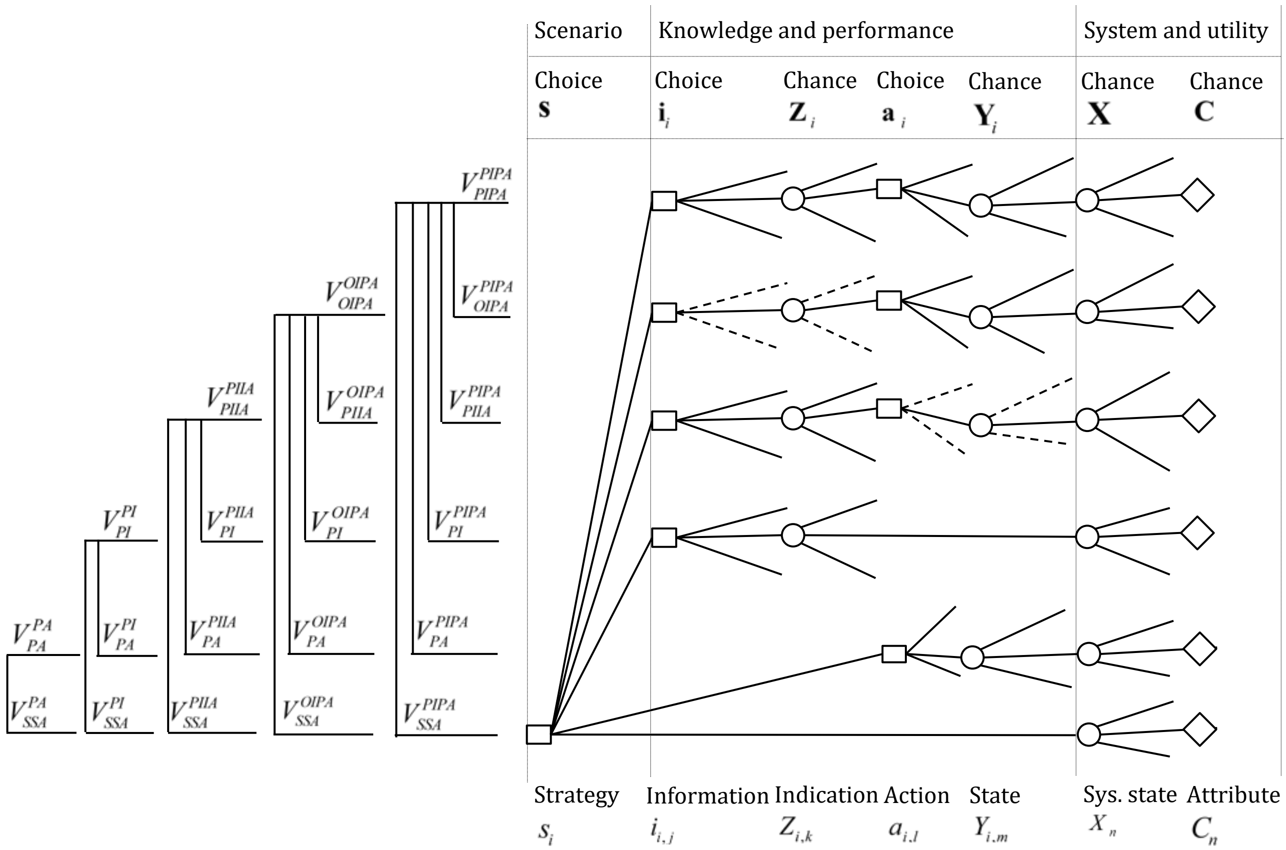

Figure 3: Decision value analyses by combining different types of decision analyses

4.1. Value of information analyses

Value of information analyses include value of predicted information, VoPI, and value of obtained information analyses, VoOI. The value of predicted information may be quantified with a base strategy of the type OIPA and a PIPA enhancement strategy:

$$V_{OIPA}^{PIPA} = U_{PIPA}^{*}\left(i_{PI}^{*}, \mathbf{a}_{PIPA}^{*}\right) - U_{OIPA}^{*}\left(i_{OI}, a_{OIPA}^{*}\right) \tag{8}$$

It is required that the sets of actions are identical, i.e. $\mathbf{a}_{PIPA} = \mathbf{a}_{OIPA}$, so that solely information cause the expected utility gain and that the obtained information are excluded from the set of the predicted information ($i_{OI} \notin \mathbf{i}_{PI}$) for consistency.

The analogues case of a value of expected information analysis (EVPI and EVSI – see Section 2) is the decision value analysis with a PA (similar to a prior decision analysis) and a PIPA enhancement scenario (similar to a pre-posterior decision analysis), Equ. (13). Here, the set of actions is required to be identical: $\mathbf{a}_{PIPA} = \mathbf{a}_{PA}$.

$$V_{PA}^{PIPA} = U_{PIPA}^{*}\left(i_{PI}^{*}, \mathbf{a}_{PA}^{*}\right) - U_{PA}^{*}\left(a_{PA}^{*}\right) \tag{9}$$

The value of predicted information can be readily quantified as the expected utility difference between a predicted information enhancement scenario (PI) and a system state analysis (SSA):

$$V_{SSA}^{PI} = U_{PI}^{*}\left(i_{PI}^{*}\right) - U_{SSA} \tag{10}$$

The value of information can also be quantified with identical decision scenarios of the types PIPA, PIIA and PI for which the sets of information acquirement strategies are not identical, i.e. $\mathbf{i}_{PI,1} \neq \mathbf{i}_{PI,2}$, but the action (sets) are identical, i.e. $\mathbf{a}_{PA,1} = \mathbf{a}_{PA,2}$ and $a_{IA,1} = a_{IA,2}$ (Equ. (15) to (17)).

$$V_{PIPA}^{PIPA} = U_{PIPA,1}^{*}\left(i_{PI,1}^{*}, \mathbf{a}_{PA,1}^{*}\right) - U_{PIPA,2}^{*}\left(i_{PI,2}^{*}, \mathbf{a}_{PA,2}^{*}\right) \tag{11}$$

$$V_{PIIA}^{PIIA} = U_{PIIA,1}^{*}\left(i_{PI,1}^{*}, a_{IA,1}\right) - U_{PIIA,2}^{*}\left(i_{PI,2}^{*}, a_{IA,2}\right) \tag{12}$$

$$V_{PI}^{PI} = U_{PI,1}^{*}\left(i_{PI,1}^{*}\right) - U_{PI,2}^{*}\left(i_{PI,2}^{*}\right) \quad (13)$$

The value of obtained information (VoOI) due to an optimal action change ($a_{PA,1}^{*}$ and $a_{PA,2}^{*}$) can be quantified in analogy to a conditional value of information analysis as the difference between the expected utilities of a OIPA (posterior) and a PA (prior) decision analysis type given identical action sets $\mathbf{a}_{PA,1} = \mathbf{a}_{PA,2}$:

$$V_{PA}^{OIPA} = U_{OIPA}^{*}\left(i_{OI}, a_{PA,1}^{*}\right) - U_{PA}^{*}\left(a_{PA,2}^{*}\right) \quad (14)$$

The difference of the expected utilities for two OIPA decision analysis types belongs also to a value of information analysis when the obtained information strategies are different ($i_{OI,1} \notin i_{OI,2}$) and the action sets are identical ($\mathbf{a}_{PA,1} = \mathbf{a}_{PA,2}$).

$$V_{OIPA}^{OIPA} = U_{OIPA,1}^{*}\left(i_{OI,1}, a_{PA,1}^{*}\right) - U_{OIPA,2}^{*}\left(i_{OI,2}, a_{PA,2}^{*}\right) \quad (15)$$

4.2. Value of Action Analyses

The types of value of actions analyses can be derived in correspondence to value of information analyses with the difference that the expected utility gain is caused solely by predicted or by implemented actions. The value of predicted actions can be straightforwardly calculated as the difference between the expected utilities of a predicted action and a system state analysis:

$$V_{SSA}^{PA} = U_{PA}^{*}\left(a_{PA}^{*}\right) - U_{SSA} \quad (16)$$

For the cases that the (sets) of information acquirement strategy are identical ($\mathbf{i}_{PI,1} = \mathbf{i}_{PI,2}$ or $i_{OI} = i_{PI}^{*}$) but the implemented actions are different from the predicted actions ($a_{IA} \notin \mathbf{a}_{PA}$), value of action analyses can refer to a PIIA base and a PIPA or OIPA enhancement scenarios:

$$V_{PIIA}^{PIPA} = U_{PIPA}^{*}\left(i_{PI,1}^{*}, \mathbf{a}_{PA}^{*}\right) - U_{PIIA}^{*}\left(i_{PI,2}^{*}, a_{IA}\right) \quad (17)$$

$$V_{PIIA}^{OIPA} = U_{OIPA}^{*}\left(i_{OI}, \mathbf{a}_{PA}^{*}\right) - U_{PIIA}^{*}\left(i_{PI}^{*}, a_{IA}\right) \quad (18)$$

The reasoning from above ($i_{OI,1} = i_{OI,2}$, $\mathbf{i}_{PI,1} = \mathbf{i}_{PI,2}$ and $\mathbf{a}_{PA,1} \neq \mathbf{a}_{PA,2}$) applies also to value of action analyses with the identical decision analysis types PA, OIPA and PIPA:

$$V_{PA}^{PA} = U_{PA,1}^{*}\left(a_{PA,1}^{*}\right) - U_{PA,2}^{*}\left(a_{PA,2}^{*}\right) \quad (19)$$

$$V_{OIPA}^{OIPA} = U_{OIPA,1}^{*}\left(i_{OI,1}, \mathbf{a}_{PA,1}^{*}\right) - U_{OIPA,2}^{*}\left(i_{OI,2}, \mathbf{a}_{PA,2}^{*}\right) \quad (20)$$

$$V_{PIPA}^{PIPA} = U_{PIPA,1}^{*}\left(i_{PI,1}^{*}, \mathbf{a}_{PA,1}^{*}\right) - U_{PIPA,2}^{*}\left(i_{PI,2}^{*}, \mathbf{a}_{PA,2}^{*}\right) \quad (21)$$

The quantification of the value of implemented actions requires a PIIA decision analysis type:

$$V_{PI}^{PIIA} = U_{PIIA}^{*}\left(i_{PI}^{*}, a_{IA}\right) - U_{PI}^{*}\left(i_{PI}^{*}\right) \quad (22)$$

$$V_{PIIA}^{PIIA} = U_{PIIA,1}^{*}\left(i_{PI,1}^{*}, a_{IA,1}\right) - U_{PIIA,2}^{*}\left(i_{PI,2}^{*}, a_{IA,2}\right) \quad \text{with}$$

$$\mathbf{i}_{PIIA,1} = \mathbf{i}_{PIIA,2} \text{ and } a_{IA,1} \neq a_{IA,2} \quad (23)$$

4.3. Value of information and actions analysis

An expected utility gain can also be caused by both actions and information. A straightforward example would be a PIPA enhancement scenario with a system state analysis (Equ. 28).

$$V_{SSA}^{PIPA} = U_{PIPA}^{*}\left(i_{PI}^{*}, \mathbf{a}_{PA}^{*}\right) - U_{SSA} \quad (24)$$

The following Table 1 includes further combinations of information and action caused decision value analyses with the corresponding information and action sets but without any distinction about the information acquirement nor the action implementation states.

Table 1: Further types of value of information and actions analyses

Decision value	Information sets	Action sets
V_{SSA}^{OIPA}	-	-
V_{SSA}^{PIIA}	-	-
V_{OIPA}^{PIPA}	$i_{OI} \notin \mathbf{i}_{PI}$	$a_{PA,2}^{*} \notin \mathbf{a}_{PA,1}^{*}$
V_{PIIA}^{PIPA}	$\mathbf{i}_{PI,1} \neq \mathbf{i}_{PI,2}$	$a_{IA} \notin \mathbf{a}_{PA,1}^{*}$
V_{PI}^{PIPA}	$\mathbf{i}_{PI,1} \neq \mathbf{i}_{PI,2}$	-
V_{PA}^{PIPA}	-	$\mathbf{a}_{PA,1} \neq \mathbf{a}_{PA,2}$
V_{PIPA}^{PIPA}	$\mathbf{i}_{PI,1} \neq \mathbf{i}_{PI,2}$	$\mathbf{a}_{PA,1} \neq \mathbf{a}_{PA,2}$

5. APPLIED DECISION ANAYSES

In the following a - non-exclusive - list of applied decision analysis is provided for an orientation of so far used decision value analyses.

5.1. Risk based inspection planning

Risk based maintenance planning encompassing inspection and repair planning of fatigue deteriorating structural systems of offshore structures has been early identified as a pre-posterior decision theoretical problem (see e.g. Faber (1997)). It should be noted that the identification of an optimal inspection and repair planning (e.g. Faber et al. (2000), Straub (2004), Schneider, Rogge et al. (2018)) contains models for the repair uncertainty – as introduced in the extended decision analysis (see Section 3). When associating the approaches of risk based inspection planning to the a value of information analysis (as partly in e.g. Irman, Thöns et al. (2017)), it can be found that base scenarios of the types SSA or PA are utilized with an PIPA or OIPA enhancement scenarios. This implies that the values of (obtained) information and of (obtained) information and actions (decision value type V_{SSA}^{PIPA}) are quantified.

5.2. Service life extension of offshore wind turbine support structures

The identification of the information precision for the service life extension of offshore wind park structures is analyzed in Thöns, Faber et al. (2017). The value of information is quantified with PIPA enhancement scenario and a base PA scenario building upon a system state analysis (SSA), which encompasses both a risk and an expected benefit (power production) analysis.

5.3. Design optimization of wind turbines

Components of wind turbines maybe proof loaded before assembled. The efficiency of various types of proof loading is analyzed in Brüske and Thöns (Accepted) by quantifying the value of information. It is further found that proof loading information facilitate new actions leading to different action sets in the PIPA and PA analysis and consequently to the quantification of the value of information and actions.

5.4. Identification of efficient terrorism mitigation strategies

The necessity of a system state analysis (SSA) is illustrated with the efficiency assessment of risk mitigation strategies for terrorism hazards. The system state analysis in the context of terrorism attacks constitutes a risk analysis for which the quantified risks are subjected to acceptance criteria. When these societal acceptance criteria cannot be fulfilled – as this may be the case for high threat probabilities – risk mitigation strategies have to be implemented. However, risk mitigation strategies may not always be efficient (see e.g. Stewart (2017), Mueller and Stewart (2016)) and require thus a careful decision theoretical assessment before implementation. The efficiency of implementing physical measures with consideration of the implementation uncertainties (Stewart (2017)) can be based on PA decision analysis or a value of action analysis (PA enhancement scenario with a SSA base). Further strategies may include surveillance in combination with consequence mitigation actions (infrastructure closure), i.e. a PIPA decision analysis (Thöns and Stewart (2018), Thöns and Stewart (Accepted)) or a PIPA enhancement scenario facilitating decision value of the types of value of information and action analyses.

5.5. Proof loading of bridges

The optimal loading level, monitoring strategy and stop criterion for the performance of a bridge proof loading test are identified with a PIPA enhancement and SSA base scenario (Kapoor and Thöns 2019). Here, the proof loading is modelled as an action with the implementation uncertainty being the probability of a test failure.

6. CONCLUSIONS

This paper summarizes the classification of value of information analyses following Raiffa and Schlaifer (1961) and introduces an extended formulation of decision analyses, which provides the basis for deriving 20 types of decision value analysis encompassing value of information, value of actions and value of actions and information analysis. The so far in civil engineering published studies in the field of decision value analyses show a diversity beyond the original definitions, however, also being less diverse in comparison to the introduced classification in this paper. With further clarification and extension of the theoretical foundation – as this has been the starting point of this paper – and the development of approaches, tools and computational efficiency together with a further penetration in standardization, industrial consulting and authority requirements, it is expected that more comprehensive and thus diverse scenarios can be analyzed and optimized. With addressing and integrating engineering and economic knowledge and performance management – as this should be the incentive of decision analyses - an decision value analysis holds relevance and requires at the same time a thorough, clear and precise understanding of the underlying models and what causes an expected utility gain.

REFERENCES

Benjamin, J. R. and C. A. Cornell (1970). Probability, Statistics and Decision for Civil Engineers, McGraw-Hill, New York. ISBN: 070045496.

Brüske, H. and S. Thöns (Accepted). Value of pre-construction proof loading information for structural design. Wind Energy.

Faber, M. H. (1997). Risk Based Structural Maintenance Planning. Probabilistic Methods for Structural Design 56: 377-402.

Faber, M. H. and S. Thöns (2013). On the Value of Structural Health Monitoring. ESREL 2013, Amsterdam, The Netherlands, 29.09.2013 - 02.10.2013.

Irman, A. A., S. Thöns and B. J. Leira (2017). Value of information-based inspection planning for offshore structures. 36th International Conference on Ocean, Offshore and Artic Engineering (OMAE), Trondheim, Norway, 25-30 June, 2017.

Kapoor, M., and Thöns, S. (2019). "A decision theoretic approach towards planning of proof load tests." (Accepted) 13th International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP), Seoul, South Korea.

Keisler, J., Z. Collier, E. Chu, N. Sinatra and I. Linkov (2014). Value of information analysis: the state of application. Environment Systems and Decisions 34(1): 3-23. DOI: 10.1007/s10669-013-9439-4.

Memarzadeh, M. and M. Pozzi (2016). Integrated Inspection Scheduling and Maintenance Planning for Infrastructure Systems. Computer-Aided Civil and Infrastructure Engineering 31(6): 403-415. DOI: 10.1111/mice.12178.

Mueller, J. E. and M. G. Stewart (2016). Chasing Ghosts - The Policing of Terrorism. New York, USA, Oxford University Press.

Raiffa, H. and R. Schlaifer (1961). Applied statistical decision theory. New York, Wiley (2000). ISBN: 047138349X.

Schneider, R., A. Rogge, S. Thöns, E. Bismut and D. Straub (2018). Inspection and maintenance planning for turbine support structures in offshore wind parks. The Sixth International Symposium on Life-Cycle Civil Engineering (IALCCE 2018), Ghent, Belgium, October 28-31, 2018.

Stewart, M. G. (2017). Risk of Progressive Collapse of Buildings from Terrorist Attacks: Are the Benefits of Protection Worth the Cost? Journal of Performance of Constructed Facilities 31(2): 04016093. DOI: doi:10.1061/(ASCE)CF.1943-5509.0000954.

Straub, D. (2004). Generic Approaches to Risk Based Inspection Planning for Steel Structures. PhD. thesis. Chair of Risk and Safety, Institute of Structural Engineering. ETH Zürich.

Straub, D. (2014). Value of information analysis with structural reliability methods. Structural Safety 49(0): 75-85. DOI: http://dx.doi.org/10.1016/j.strusafe.2013.08.006.

Straub, D., E. Chatzi, E. Bismut, W. M. G. Courage, M. Döhler, M. H. Faber, J. Köhler, G. Lombaert, P. Omenzetter, M. Pozzi, S. Thöns, D. Val and D. Zonta (2017). Value of Information: A roadmap to quantifying the benefit of structural health monitoring. ICOSSAR 2017, Vienna, Austria

Thöns, S. (2018a). On knowledge and utility management. 10th International Forum on Engineering Decision Making (IFED), Lake Louise, Canada.

Thöns, S. (2018b). On the Value of Monitoring Information for the Structural Integrity and Risk Management. Computer-Aided Civil and Infrastructure Engineering 33(1): 79-94. DOI: 10.1111/mice.12332.

Thöns, S., M. H. Faber and D. Val (2017). On the Value of Structural Health Monitoring Information for the Operation of Wind Parks. ICOSSAR 2017, Vienna, Austria

Thöns, S. and M. Stewart (2018). Assessment of Terrorism Risk Mitigation Measures for Iconic Bridges. IABMAS 2018 - 9th International Conference on Bridge Maintenance, Safety and Management, Melbourne, Australia, July 9-13, 2018.

Thöns, S. and M. Stewart (Accepted). On Decision Optimality of Terrorism Risk Mitigation Measures for Iconic Bridges. Reliability Engineering & System Safety.

Yokota, F. and K. M. Thompson (2004). Value of Information Literature Analysis: A Review of Applications in Health Risk Management. Medical Decision Making 24(3): 287-298. DOI: 10.1177/0272989x04263157.