A Reference Model for Engineering Asset Management Excellence

Oliver Schmiedbauer(✉) and Hubert Biedermann

Department Economic and Business Management, Chair of Economic- and Business Management, Montanuniversitaet Leoben, Leoben, Austria
{oliver.schmiedbauer,hubert.biedermann}@unileoben.ac.at

Abstract. The ever-increasing automatization within the manufacturing and producing industry during the past decades lead to the necessity of a more holistic view on asset related processes. Industrial companies meet this with transforming their maintenance departments into strategic, life-cycle-oriented asset management organisations. Furthermore, since the beginning of the 1990's, excellence models, like the EFQM model gained more and more popularity. One reason for the popularity of these models is, that they provide structure for improving a management system. They usually include two sub-models, one, consisting of criteria that describe activities of an excellent company and another one, to evaluate the maturity of the company's processes with respect to the criteria. Furthermore, the gained qualitative and quantitative results are translated into a score that can be used for benchmarking purposes. This paper presents a reference model, that, using the principles of design science research, combines the two aforementioned concepts of engineering asset management and excellence. The purpose of this reference model is to enable companies to effectively implement and improve an asset management system.

1 Introduction

Already before the COVID-19 pandemic and the Ukraine War, industrial companies were submitted to a rapidly changing environment, which pushed the importance of strategic Engineering Asset Management (EAM) in asset intensive industries (Komonen *et al.* 2012). The crises of the past years have further driven top management towards higher expectations of their EAM competence, with mere short-term cost-effectiveness of associated projects losing importance as a selection criterion (Mills and Pudney 2021). EAM is starting to be recognised as a core competence in industries, where improvement of related processes presents a major lever for increasing company efficiency and effectiveness (Mills and Pudney 2021). Based on these developments, in recent years concepts have been developed that call for a holistic view of engineering asset and maintenance management and combine approaches such as lean, learning orientation, dynamization, risk and value orientation using, among other things, the possibilities of new technologies (Kinz *et al.* 2016; Schmiedbauer *et al.* 2020). It is recognised that a new model is needed that can map and evaluate the requirements of a management system based on these approaches and thus serve as a starting point for improvement by closing control

A. Crespo Márquez et al. (Eds.): WCEAM 2022, LNME, pp. 301–311, 2023.
https://doi.org/10.1007/978-3-031-25448-2_29

loops (Kinz 2017). In this paper we present a structured approach to improve the EAM of industrial companies. Design Science Research (DSR) according to Hevner was chosen as the methodological approach. DSR is an iterative approach, consisting of a relevance, a rigor and a design cycle to design new artefacts (Hevner 2007). The designed artefact is the EAM excellence reference model, the relevance cycle focused on the applicability and the usefulness for producing companies and the rigor cycle on relevant literature reviews on EAM and excellence models. The design cycle consisted of several iterations of applications of evaluation models in central European companies.

2 Engineering Asset Management and Excellence

EAM and Excellence are concepts that have been widely discussed but never integrated on a model basis. EAM is an area that unites a variety of complex processes under itself and calls for a holistic approach to them (El-Akruti and Dwight 2013; Emmanouilidis et al. 2013). Excellence models (EM) are models, whose architectures are suitable as a basis for fulfilling this very requirement. EAM is defined as, *"the system that plans and controls the asset related activities and their relationships to ensure the asset performance that meets the intended competitive strategy of the organization"* (El-Akruti and Dwight 2010). EAM encompasses comprehensive system control and takes a holistic and life cycle view on asset related activities, which are directed at achieving the organisations goals (El-Akruti and Dwight 2013; Emmanouilidis et al. 2013). EAM includes all practices that are needed to sustainably, optimally and risk-oriented manage an asset (Burnett and Vlok 2014). It combines technical and business activities and, given the context of asset intensive industries, should be part of the overall corporate strategic management (Komonen *et al.* 2012; El-Akruti *et al.* 2016). Nevertheless, also normative, or cultural aspects have to be considered when approaching EAM (ISO 55000 2014). EAM processes can be grouped by and encompass the following aspects: strategy, planning, evaluate/ design, create/ procure, operate, maintain, modify, and dispose of. Decisions around capital planning and budgeting as well as the operating budget are part of EAM, which stresses the necessity for a strategic approach towards EAM. EMs are at the focus of the Excellence concept. Most models are developed by national or regional organizations and serve as the basis for quality awards (Dahlgaard et al. 2013). These models are sometimes very similar and most of them share several common characteristics. They are built on fundamental principles that provide a normative outline for the rest of the model. Among other things, these are principles that are strongly based on current management theory or that reflect the cultural background of the model creators. An excellence model consists of a criteria model, in which the traits of excellent organisations are described, and a scoring model that assesses the degree of fulfilment of the criteria and that is usually capable of translating this assessment into a single point value that can be used for benchmarking purposes. Both the inputs, i.e. how the normative, strategic and partly also operational process levels are designed, and the results, which usually have to be presented in the form of key figures, are considered. In this way, control loops for continuous improvement of the management domain under consideration are being closed (Nenadál 2020; Fonseca 2021; Saunders *et al.* 2008). Due to their characteristics, they are sometimes also referred to as performance measurement systems (Ritchie and Dale 2000).

3 A Model for EAM Excellence

The model is designed for the use by profit-oriented industrial enterprises producing goods of any kind and service workshops. All other types of enterprises and industries are not considered as target groups of this model. The EAM-EM builds on a few fundamental principles. It is furthermore comprised of a criteria model, which is closely linked to an evaluation model. An existing process model is used for assessment projects that are starting points for EAM-EM implementation. An abstraction of the EAM-EM can be viewed in Fig. 1.

The fundamental principles include systems thinking, stakeholder-, value-, risk- and learning-orientation as well as designing for dynamic environments. It is however recognised, that companies from different branches, with different production types and asset intensities, have to find their own interpretation of these principles. The excellence definition for the model was chosen as follows:

Excellent asset management always achieves outstanding results in terms of value creation and all relevant stakeholders through fully closed control loops at the normative, strategic as well as operative level.

The criteria model consists of nine categories on the enabler side, which encompass processes from the normative, via strategic to operative management. Each of these categories is comprised of a set of sub-categories, within which activities of EAM organisations are described.

The category Philosophy & Target System considers how asset management is integrated into the corporate philosophy, the process of identifying relevant stakeholders and megatrends and how an asset philosophy, like e.g. a lean, or a smart philosophy, is derived from it. Furthermore, it looks at enablers, like the quality management system, digitalisation concepts and their relevance for EAM. The derivation of an organisation specific mission statement, which is the long-term normative base for asset related decisions is dealt with in another sub-category. A further sub-category discusses the target system, how it is derived from the philosophy and mission statement, how it is designed, if control loops are closed and how it is documented.

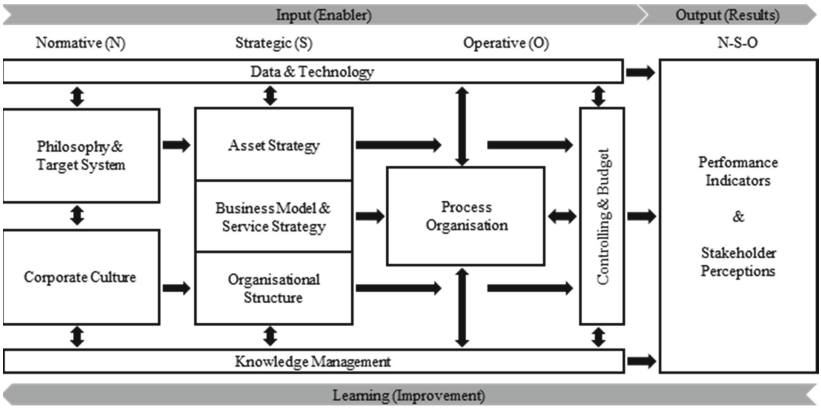

Fig. 1. Engineering asset management excellence model (EAM-EM)

Corporate Culture looks at different cultural enablers. The first sub-category deals with processes around employee motivation, which includes the collection of related data, the derivation of actions, the recognition and appreciation of performance, and approaches around ex- and intrinsic motivation. Another sub-category looks at the ability to change & Change Management, if the employees understand the necessity to change, if there is a standardised change management process and comprehensive change support, which kinds of change instruments are being used and if the change processes themselves are being improved. The third sub-category discusses communication processes, if there is a communication plan for horizontal and vertical communication, if information flows are being hindered, how problems are discussed and how digital platforms are being used. The last sub-category looks at leadership related processes and the leadership style of managers.

Business Model & Service Strategy is a category most relevant in large and service organisations, which sell their services to external or internal customers and the category describes the strategic perspectives of the related processes. First, it focuses on the relevant stakeholders, especially on the needs of the customers and how other partners, like suppliers are included in the processes. The second sub-category focuses on how the service strategy is derived and how services to be sold are chosen. The last category focuses on the service process itself, how stakeholders are included, if there is e.g. a catalogue of best practice services and how the topic of service innovation is being approached.

Asset Strategy focuses on the strategies related to the organisation's own assets. The first sub-category discusses investment, maintenance prevention and life cycle management related processes. This includes if life cycle thinking is embedded in the management processes and if related methods, like life cycle costing are being used and furthermore, which asset specific stakeholders are included during the investment phase to e.g. ensure high maintainability of the assets. The second sub-category deals with maintenance strategies, if there is a kind of criticality assessment that precedes a structured approach to choosing maintenance strategies, if breakdown costs are being considered and if there is a structured approach to choose the optimal strategy mix. The next sub-category considers the strategic outsourcing related processes. This includes the consideration of core competences, the structure of the outsourcing process itself, transactional costs, cooperation management and the generation of knowledge from processes, which are outsourced. The last sub-category in this category considers all spare-part related processes. It includes the question on how procurement, warehousing and supply strategies are chosen for individual spare parts, how risk assessments are used, if changes in maintenance strategies are considered, how technologies like mobile devices are integrated into the processes and how direct and indirect storage costs are calculated.

A focus of organisational structure is how the asset organisation is integrated into the company and how it interacts with other departments. The first sub-category looks into the process of structuring, how the organisation is integrated into the company and how it is decided if a service should be e.g. available from a central workshop, or a decentralised unit. The second sub-category looks at the organisational interfaces between EAM related organisations, if there is a strong functional separation, if strategic

support processes, like IT and controlling are somehow integrated as well as if and how autonomous maintenance is implemented. The third sub-category deals with workshops and social spaces, where the workshops are located, if there are on-site workshops and if there are social spaces that can be used by all employees, or only certain functions.

Budgeting & Controlling focuses on processes associated with financial streams and different indicators. The fist sub-category looks at the budgeting process, who is responsible, if it is future oriented, how risks are considered and if the budgeting related control loop is closed. The second sub-category looks at how activities and different cost types are allocated to cost centres and the quality as well as granularity of these allocations. The third sub-category focuses on reporting and controlling related processes and if they are enablers for continuous improvement. The last sub-category deals with performance measurement and indicators. It analyses the performance measurement approach chosen and how it is integrated into controlling related processes. Other questions asked include if indicators are current, can be calculated alongside process execution, if there is a benchmarking process implemented, and how relevant indicators are communicated at shop floor level.

Process Organisation deals with the operative processes. The first sub-category discusses how EAM processes are described and included in an overall management system, the granularity of process descriptions, how processes are continuously improved and if maintenance quality can be measured besides efficiency and effectiveness indicators of operative processes. The second sub-category deals with operative planning, if the corresponding processes are standardised, how the granularity of a specific planning activity is chosen and how and how good cross-departmental planning works. The third sub-category discusses execution related processes, which includes how the execution system is designed, how data is collected during related processes, how the processes are supported by technologies and how the criticality of assets influences prioritisation. The fourth sub-category asks questions on the quality of the documentation, which operative workers need for the execution of processes and how a high quality is assured. The next sub-category looks at the operative third-party service processes, if they are standardised, how the quality of work is evaluated and if there is some technological support, e.g. via mobile devices. The last sub-category in this category analyses the continuous improvement processes (CIP), how the CIP are designed, which pre-conditions need to exist to start a CIP, how the processes are integrated into the overarching knowledge management system, which tools are used during the process and how employees are integrated into the process.

Knowledge Management is a category that interacts with all other categories, which is also the reason, why some sub-categories mentioned before contain elements of knowledge management and a learning orientation. This is the case, because improvement and the generation of knowledge, are necessary throughout all processes. The first sub-category deals with the aspect of if and how a learning culture is developed in an organisation. Important aspects of this sub-category include if employees are motivated to learn, how knowledge is passed on to new employees and how knowledge is exchanged with the external environment. The second sub-category looks at the coordination of knowledge. This includes the assignment of responsibilities, the abstract representation of knowledge within the organisation, the systems that aid knowledge management and

the externalisation of knowledge. The sub-category qualification management takes a look at how the qualifications of employees are documented, if they are linked to job descriptions and if e.g. a qualification matrix enables cross-departmental knowledge coordination from a strategic perspective. The fourth sub-category considers training related processes, the comprehensiveness of a training programme, how employees are included in the creation of the training programme and if methods like job rotation are being used. Furthermore, it looks at the types of trainings available, e.g. if there are trainings for problem solving, data analytics as well as digitalisation basics available, or not.

Data & Technology is the second category that interacts with all other categories. Normative enablers are needed to enable the comprehensive digitization of a company and strategic and operative processes can be supported by different technologies and data. The first sub-category discusses enterprise asset and computerised maintenance management systems. This includes the comprehensiveness of the system, the integration with other systems and the usability of the software. The second sub-category deals with data management related processes, how data is mapped, if the available data supports the processes across the complete management cycle, how data goals are defined and to which extent data is used. The second sub-category deals with the aspect of data quality, which includes how it is being optimised, how data is being recorded, if metadata is available at a high quality and if the plausibility of data is being checked. The comprehensiveness of data, which can also be considered an aspect of data quality, is the next sub-category. It deals with documentation and the related processes throughout EAM. The last sub-category is concerned with analysis related processes, which includes the capabilities around, descriptive, diagnostic, predictive and prescriptive analysis, visualisations, dashboards and if methods from the operations research domain are in use.

The results category includes all kinds of indicators, which should be chosen while considering the context of the organisation. Possible indicators include normative, strategic and operative indicators. Examples are e.g. cost related indicators, like direct and indirect maintenance costs, life cycle costs, transactional costs and others. Furthermore, indicators that describe the efficiency of processes, the maintainability of assets or the effectiveness of chosen maintenance strategies. Other indicators could include employee satisfaction, employee fluctuation, indicators around knowledge generation or externalisation as well as indicators that describe the effectiveness of learning processes. Other indicators could measure safety, health and environmental aspects as well energy efficiency.

The first step in assessment is to conduct an analysis of the context of the organisation under evaluation to understand why an organisation designs its processes the way it does and what excellence actually means in its context. The evaluation model both evaluates the inputs, as described by the criteria model, as well as the outputs, represented by different indicators at sub-category level. On a meta-level, the six maturity levels can be described as follows:

0. Incomplete
1. Initial
2. Managed

3. Standardised
4. Quantitatively Managed
5. Optimised
6. Excellence

The inputs are evaluated using a logic based on a maturity model architecture. The logic builds on the evaluation logic of the Baldridge Excellence Framework (BEF), the logic of the model of the European Foundation for Quality Management (EFQM), and the Capability Maturity Model Integration (CMMI). (See Baldridge Performance Excellence Program 2021; EFQM 2019; CMMI Product Team 2010) Each maturity level is defined according to four process attributes:

- Procedure
  - The methods used in the process
  - The usefulness of the methods, which must be clearly justified
  - Effectiveness and efficiency of the methods used
  - The degree of systematisation or standardisation of the approach
- Implementation
  - The approach is implemented in relevant areas in an effective and efficient manner
  - The approach is used consistently across the board
  - The approach allows for a certain degree of flexibility and adaptation
- Evaluate & Improve
  - The existence of indicators as enablers for learning processes
  - The degree of control loop closure for single- and double-loop learning
  - The introduction of best practices and innovations to improve the approach
  - The exchange with the internal and external environment for sharing best practices
- Integration & Alignment
  - The approach is aligned with the goals of the company, asset management and other stakeholders
  - The approach is aligned with other asset management subsystems and is part of one or more higher-level control loops
  - The information systems of the process are integrated into the higher-level information system
  - The process is harmonised with the processes of other departments, divi-sions or companies.

As an example, the description of the procedure in the second maturity level is, “An effective, systematic, but not yet standardised approach that addresses the basic issue of the subcategory is evident.”

The outputs are interpreted using different metrics derived from the evaluation models of the BEF and EFQM model, which translate the indicators into a maturity score, analogue to the one for the enabler categories:

- Approach
  - The indicator measures the achievement of a set goal and the performance of the organisation
  - The given data quality allows for meaningful insights
- Trend & Level
  - Positive trends, or sustained outstanding performance are achieved over a strategic cycle
  - Good performance compared to an (external) benchmark
- Targets
  - Appropriate targets that are in line with the strategy
  - Set with benchmarks in mind
  - Future-oriented target setting
- Integration
  - Based on current cause-effect relationships
  - Component of one of the most relevant control loops
  - Combination of leading and lagging indicators

Each maturity level is assigned a percentage range, which the assessors use to translate the evaluation results into quantitative values. The sub-categories within a category are equally weighted, while the categories have different weights. All in all 1000 points can be reached and they are distributed as follows:

- Philosophy & Target System: 50
- Corporate Culture: 50
- Asset Strategy and Business Model & Service strategy (combined): 200
- Organisational Structure: 50
- Process Organisation: 100
- Controlling & Budget: 50
- Knowledge Management: 100
- Data & Technology: 100
- Results: 300

Until this point, the reference model for engineering asset management excellence was discussed. This model can already be used to evaluate an organisation, however, an

adoption to a specific company in the form of an application model, can be realised. A reason for such an adoption is often that the category Business Model & Service Strategy cannot be applied, since no services are being offered. For other organisations, certain sub-categories, or items will not make any sense due to the organisational context or the chosen Philosophy. Furthermore, if the model is used as a comprehensive management system and an improvement tool, the definition of detailed, organisation-, and sub-category-, or item-specific maturity levels is recommended.

The process model for a project to implement the EAM-EM, is strongly focused on qualitative evaluation as well as improvement and consists of six phases. The first phase is the project preparation phase, in the second phase the combined criteria and EMs are used for evaluation and to define the as-is state. In a third phase, a target state, which includes maturity levels and strategies, is defined and in the fourth phase actions are derived from a gap analysis between target and as-is state. In the fifth phase, these actions are prioritised and planned according to different criteria (Maier *et al.* 2021). Finally, in the sixth phase, the actions are implemented and the full EAM-EM is introduced as a means to continually control progress and further optimise the relevant systems and processes.

4 Case Study

The model was used for evaluation in various central European organisations, in this paper the authors describe the case of a large and asset intensive company. During this project, the aforementioned process model was used. The evaluation of the as-is state resulted in values in the low to medium range of the model scale. The targets were set in the medium to high range and a set of strategic areas of improvement were defined, like e.g. further standardisation across departmental and sub-company boundaries, digitalisation, leveraging knowledge management and others. This resulted in a set of actions to be implemented in the near future. The interrelationships between the actions were examined, their importance and duration evaluated, and the cost-benefit ratios were assessed in monetary terms. On this basis, the measures were prioritised and programme planning was carried out. Currently, the first actions are being carried out, next steps include implementing the full EAM-EM, which includes integration in the overall management system and the creation of a new performance measurement system for quantitative evaluation.

5 Final Remarks

Coming from the increasing importance of a structured approach to EAM over the past years and decades, there has been a growing demand from the industry for methods and tools that support companies in developing their EAM in a targeted manner. For this purpose, the EAM-EM has been developed. At its core, it builds on fundamental principles, combines a qualitative with a quantitative evaluation, enables the closing of control loops for continuous improvement and supports organisational development. The model has been validated in various companies and next steps include the use of it as a tool for benchmarking across companies and finally, to continually improve it.

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