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An Empirical Approach to Model Formulation for System Support Engineering

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Abstract Organizations today face intense competitive pressure to maximize their performance over time as customer expectations increase. The literature suggests that there is a need to develop a tool or techniques that practitioners in the industry can apply to help in support system design for operating assets as a long-term service solution in order to maintain optimized performance and obtain the best return on investments. This technique should integrate the industry domain knowledge to create and deliver support solutions for in service assets. There is no generic architecture for system support engineering available for practitioners to use. This will lead to the following question "Can industrial practitioners have a generic architecture to simplify the development of such a system"? If the answer is yes; then how possible is it? Therefore, this paper will present an empirical approach to model the formulation for a system support engineering (SSE) generic framework. The development of the SSE Framework combines both literature analysis and empirical work. Also, it will provide a possible answer to the research question and suggest further recommendations and opportunities for future research.

Keywords System Support Engineering, Model Formulation, Support Solution, Generic Framework

1. Introduction

Organizations today face intense competitive pressure to do things better, faster and cheaper. This pushes organizations to improve their performance over time, while meeting (or catching up with) increased customer demands and competitor pressure. Classical techniques in asset management involve performance monitoring, process control and fault diagnosis techniques that aim to determine the limit of the asset's service life. Theoretically, replacements should be made at the time when the asset is about to fail so that the full service value of the asset can be utilized. However, this is not possible as modern machine systems are of increasing complexity and sophistication. Many other factors govern the operation of the asset. Most factors, such as opportunity costs or lost customers, are difficult to quantify and measure. Many asset management decisions are made on rules of thumbs rather than using analysed system performance data. Decisions such as asset replacement,

upgrade or system overhaul are in many respects equivalent to a major investment, which is risk sensitive.
A high value engineering complex system is expected to be in service for years. Therefore, in order to meet functional demand by the end users, the capability and efficiency of the system should keep increasing [1]. In general, more the complex systems have become, the more better solutions in both technical and management domains is required [2]. The literature suggests that there is a need to develop a structure that practitioners in the industry can apply to help in support system design for operating assets as a long-term service that maintains optimized performance and achieves the best return on investments. This structure should integrate industry domain knowledge to create and deliver a specific support solution for in service assets, as the circumstance requires.

This leads to the following research question "Can industrial practitioners have generic architecture to simplify the development of such a system"? If the answer is yes; then how possible is it?

The development of such a structure combines both literature analysis and empirical work. The analysis approach is shown in Figure 1.

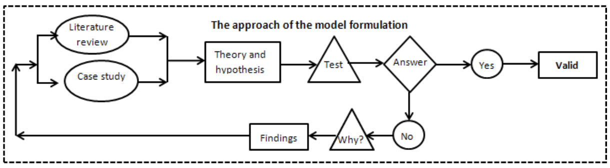

Figure 1. Approach overview

The literature analysis provides information on how different systems work and what has been done so far in this field. Also, it gives a sense of what needs to be done and highlights the level of understanding that needs to be gained from the empirical work and the required steps for that.

Table 1 displays a summary of knowledge elements, on asset technology and service knowledge, which have been extracted from the cases reviewed in literature so far.

Due to the complexity and dynamicity of system support in modern industries, the analysis starts from a case study to achieve reasonable assessment of the support system with a focus on engineering concepts. Reviewed cases and literature showed that collecting conscious-based data through self-reporting is not good enough to achieve high accuracy information. Therefore, the mentioned methodology was combined with interpolation from people involved in the studied system to describe their professional understanding and thinking. This will inject the collected data with some sort of predictive validity to a reasonable extent. In addition, through visiting modern industries and reviewing published case studies, the researcher found that the framework in this regards should have:

- Clearly identified requirements.
- An overview of the behaviour vector of the model and clearly drawn relations between elements.
- Framework captures the strategic decisions, inventions and engineering trade-offs.
- All activities associated with various phases of the effort at the level of elements in the system breakdown structure.
- Technical and commercial issues that are linkable from the maintenance point of view.

Literature	Core and domain knowledge	On asset technologies	Service knowledge
A study on the logistics and performance of a real virtual enterprise [3]	Enterprise design	Integrated logistics support	System architecture and Knowledge management
System Support Based on Signal Diagnostic Methods [4]	System Engineering	Remote control	System monitoring
Globally Distributed System Virtual Enterprise [5]	Information systems, Supply chain and management	Maintenance Engineering and Reliability	Customer relation, Team building and Project management
Risk Assessment of a Performance Based Contract [6]	Logistics Engineering and Risk Analysis	Enduring system design	Project management

Table 1. Classification of the knowledge elements relevant to SSE Framework

This paper will discuss the development of the system support engineering (SSE) framework as a fundamental structure for providing a systematic modelling approach that enables industrial practitioners to design a life support system.

2. Literature review

There are many research efforts suggesting different solutions and methods to improve performance in relation to the manufacturing industry:

- Manufacturing Servitization: which aims to improve the innovation ability of an organization to improve joint value through a shift from selling products to selling service systems with their product [7].
- Product-service system (PSS): which aims to design and market well-matched services for itemized

products and indicates that collaboration between team members of teams working within different locations and professions should occur [8].

- Unified Service Theory (UST): which basically aims to standardize the customer feedback of the service design methodology [9].
- Complex Engineering Service (CES): CES is defined as "systems that aim to deliver value to the customer through a system of people, processes, assets and technology and the interaction between them rather than the function of the individual components themselves" [10].
- Activity based Framework for Services (ABFS): is an activity-based approach aiming to support cross-disciplinary efforts in service researches [11]. It provides an idiosyncratic tactic general understanding of the service system concepts in multi-disciplinary organizations. However, it aims at general understanding and communication rather than being an unequivocal verified or validated description.
- Synthesized Framework (SF) [12]: using this approach, which implements qualitative and quantitative risk analysis techniques through Monte Carlo simulation, the process model and risk drivers can be analysed.

All of the presented research is unique and highly innovative but there are issues that prevent full implementation. One of the issues is that none of the research has looked at the depth of engineering. They are high-level conceptual frameworks and have diminutive depth consideration of elements of a service system on how the elements might interact. Therefore, a cohesive body of knowledge to support practice seeking solutions to a general problem with a particular scope is needed. This integrated industry domain knowledge is defined as "Systems Support Engineering" [6].

System Support Engineering (SSE) builds on Systems Engineering principles and integrates other industry knowledge, including logistics engineering, supply chain management, maintenance engineering, enterprise modelling and other competencies, to create and deliver support solutions for in-service assets. The fundamental construct of SSE framework consists of three elements (product, process and people) interacting within a business environment. This fundamental construct represents one level within the overall enterprise structure of the support solution. SSE framework adopts a multi-level modelling approach and defines a support system in three levels: enterprise, management and execution.

The system support engineering approach aims to develop a model to sustain constant high performance. This model should capture strategic planning and operation issues [13]. This model will demonstrate the performance of three elements (product, process and people) and the communication between them within an environment. Valuable information for reliable performance measurement analysis can be introduced. This will also cover the details and information required to measure the performance through all the levels within an organization. Through a systemic approach, the relationships, information exchange and future upgrades and integrations will be organized via this model.

3. The system support engineering framework view

Through the literature review, the SHEL model (Edwards, 1972) seems to be useful starting point for building the SSE model. It generalizes the relationship between the software, hardware and liveware (human) within an environment. The literature shows that the SHEL model was used as a framework conceptual model in much published research, all in regard to safety issues [14-18]. None of the mentioned research tried to expand on Edward's model. This research will use the Edward model as the start of building a basic conceptual model of the SSE generic framework.

Reviewed case studies and industrial visits indicate that one level of 3PE model is not sufficient because it will cover only the execution level and ignore the middle and higher management levels. There is always a need to present and exchange new and creative ideas between all management levels [19]. Therefore, the multi level 3PE model is introduced to address these issues and structure the communication between deferent levels.

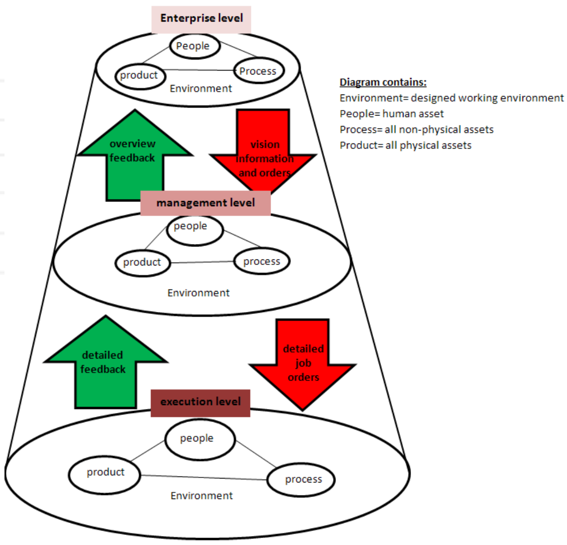

Figure 2. General vision of system support engineering framework (multi-level 3PE)

2.1 The execution level

Figure 3 shows the level of execution. The designed environment of this level is usually the workspace (i.e., a plant) where all the activities are performed. It may have different facilities like: a shop floor, a maintenance yard, a quality lab, etc. The environment should be designed to accommodate all planned activities. This environment is subject to changes overtime to suit changes in activities and to keep cost to a minimum. Also, it subjected to continuance optimization overtime.

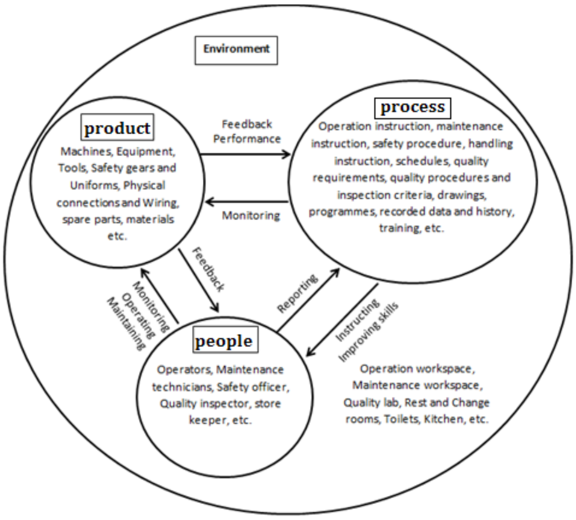

Figure 3. General vision of the 3PE model of execution level

2.1.1 Product element at execution level

Product: all the physical items.

1. Machines: this includes machines used for production, which include both direct value added, or non-direct value added machines (i.e., CNC machines, reactors, pumps, compressors, etc.).
2. Equipment: this includes all the equipment, which is not used in production (i.e., computers, phones, testing devices, forklift, etc.)
3. Tools: this includes all the tools used to do the job, such as production tools, maintenance tools, inspection tools, etc.
4. Safety gear and uniforms: all the safety equipment and wares, which are required for protection when the job is performed or in case of emergency.
5. Physical connections: this includes all the connections used to connect the production line to a power source or connect the production line components such as pipe lines, wires, etc.
6. Spare parts: the spare parts can be divided to produce spare parts and maintenance spare parts. The production spare parts are basically the parts that are normally consumed during production as part of the production process like, for example, sanding belts, etc. The maintenance spare parts are the parts that are only used during the maintenance process.
7. Materials: include all the materials used during production and maintenance.

2.1.2 Process element at execution level

Process: all non-physical items will be under this category.

1. Operation instructions: this will cover all the procedures of operation, such as setup instruction, how to operate the unit or machine, the operation parameters, etc. Practical experience and the literature review indicate that operation instructions should be clear and the simplest language and phrases should be used. Also from professional experience, combining the instruction steps with clear pictures and drawings will have a significant positive effect on the operator understanding. The operation instruction should give a clear handy reference to be used at any time by the operator. This could considerably reduce the percentage of operation errors and improve the operation performance. All the signs and names of all the items, buttons and components that are mentioned in the instruction should be clearly visually marked and labelled with the same terms as in the instructions. The operation instructions should have all the details required for safe operation and should be placed in a known and easy to reach place for the operator. The instructions should be continually updated and reviewed over time as a standard procedure of operation instruction. Operation instructions should have a detailed explanation of the production strategy and policy, like, for example, if the production is following a time strategy only, how this strategy is practically implemented and fit with the current or daily operation practice.
2. Maintenance instruction: this should instruct the technician about how to perform maintenance and troubleshooting. This should clearly instruct the process of protective (scheduled), corrective and proactive maintenance. The process should use simple to understand language combined with indicated pictures and drawings where possible. The instructions should always be updated as part of the maintenance policy. They should include a clear explanation of the maintenance policy.
3. Safety procedures: this should include all the safety procedures and policy inside the plant and also clear instructions for a state of emergency. Furthermore, it should comprise a description of the safety gear and how it can put on and operated. It could be a good idea to mention the amount of protection that the safety equipment provides as part of motivation to wear them.
4. Handling instructions: this could be part of the previous instructions as it falls under all of them but in some industries handling is a critical process. Therefore, handling instructions should cover all the handling procedures and policy. They should clearly

indicate the handling parameters and use simple language combined with pictures and drawings. It is more important to include pictures and drawings in this set of instructions because handling usually has greater varieties and critical orientations.

5. Schedules: this basically is the scheduling information for operation, maintenance, delivery and training.
6. Quality requirement: this will cover the quality requirement for operation, maintenance and products. Also, it could include quality requirements for all workspaces. The quality requirements should indicate the quality policy, objectives and vision. They should be updated as part of the requirements. It can be part of the total quality management system of an organization. The process level and management level share the same quality model mentioned earlier.
7. Quality procedure and inspection criteria: this should cover the quality inspection detail procedure and instruction for individual processes or products. This could be applied to operation, maintenance, safety and the final product.
8. Drawings: there are different types of drawing. Production drawing, which shows the product specifications. Operation drawings, which clarify or further explain the operation process, like how to operate a machine or a program and the operation layout. Maintenance drawings, which are the guidance for the maintenance process and machine structure. Also, there are safety drawings, which show the emergency exists, safety equipment and how to wear the safety gear.
9. Programs: this means the computerized software, which is used to run or assist the worker to run processes, machines, or even communicate either to follow workers or higher management. It can be classified in three main streams:

a. Operation and management programmes: which cover all the programmes for operating or managing a process. For example: managing quality, control parameters, etc.
b. Communication and recording programs: this will cover all the programs used to exchange or store information. For example: SAP, PRONTO, HR, etc.
c. Training programs: this mean the programs used as educational and training references for workers. Even though it is not a common at this level, there are some companies starting to keep this type of software in a library, which is accessible by all workers to be used as a reference and skills improvement tool.

10. Recorded data and history: this is a very important asset to keep, maintain and update because it provides important information, which is highly needed to obtain or take action. Literature and filed observations show it is a reference point for decision-making. As the organization progresses overtime it will start to build a reserve of records. The records contain information about operation, maintenance, performance, demands, etc. This information should be categorized, maintained and updated in a manner where it is easy for the user to get the needed information in a minimum time and in a clear format. For the process level, the types of records that need to be accessed are the maintenance, operation history, product data and stock items.
11. Training: this contains all the training contents, requirements and development for process level workers.

2.1.3 People element at execution level

"People" means all the humans working in the level or having an interaction with the level. Literature and case studies show that humans are the most dynamic assets an organization can have. Supporting skills improvement and developments could be one of the main challenges facing system support engineering as humans vary in learning abilities and capabilities and motivation for development. In addition, humans can leave or quit at any time. Support systems for liveware should consider changes over time and the requirements for further development and introduction of new products or upgrades and integration, plus innovative new management methods and work cultures to accommodate the need for development and performance. System support for liveware aims to introduce a long-term solution to support the liveware asset ability to perform the requirements with minimum cost and in the most sustainable way. In this level, the support system will look at how to support operators focusing on the operation point of view. Also, it will aim to polish the maintenance skills of the maintenance specialists', whether they are internal or outsourced, in both types of support system, mainly designed with considering the most cost effective sustainable outcomes. The capability and rules of occupational health and safety officers are one of the key factors in avoiding the loss of the human assets and maintaining a better shape of this asset. Systems support engineering should design a sustainable systemic technique to ensure the continuing circulation and escalation of knowledge between people in order to sustain them and increase their economic value.

2.1.4 The communication between the assets within the environment in execution level

The communication efficiency and effectiveness between the assets is a key factor toward full integration and better holistic performance outcomes of the system. A previous five case study conducted by Seshasai [20], in which the studied companies have a particular focus on providing knowledge intensive engineering services to customers, shows that a communication framework can be used to assess the sustainability of the virtual enterprise and assist supply chain partners to consider whether they should invest to attain the acceptable level of competency to join. The same concept could be applied in the support system case, but between the three assets within the support system engineering framework of an organization. Therefore, the nature of communication should be identified in order to select an appropriate communication method, procedure and tool to ensure the effectiveness and efficiency. The categories of the communication between the assets are discussed below.

2.1.4.1 Between Product – Process

The communication nature between the product– process is divided into three main types:

1. Order and information feed: where the software will tell the machine what to do and how to do it. Also, the machine can feedback the software to adjust itself or be adjusted by a third party.
2. Monitoring: for this the software usually screens for two things: the machine outcome and status. The machine status can be monitored for in operation control and onsite maintenance assessments. The direct outcomes are observed in order to ensure quality and production level. This could also work the other way around, where the hardware becomes the indicator of the software accuracy, efficiency, reliability and performance.
3. Interface: in some cases the software is just the crossing point of the hardware.

2.1.4.2 Between Process – People

In the process level the relation between the process and the people is classified in two streams:

i. Information providing: as is shown in the previous diagram, the process cotenants provide the people with reference, guidance and education. Therefore, it is important for the system support engineer to ensure that the communication system is clearly displaying understandable and easy to find information.
ii. Recording: this requires a clearly identified recording format. This format should give attention to important information. The system format cannot exactly tell what the important information is as they are different from process to process but it could highlight the classification of the important information by following some sort of grouping technology.

2.1.4.3 Between People – Product

The interaction nature between the product and the people in this level depends on the activity performed. In some cases there is a clear boundary between the people and the product, for example when operating a machine. However, sometimes they act as one component, for example when a technician wears safety gear.

This relation could be classified in three types:

1. Operation: in this relation the borders between the two assets are clearly featured and controlled. This is commonly known as man-machine interface [21]. It also covers other activities like monitoring processes, changing dyes and making tools. Here system support engineering is the aim that will be concentrating most in decision-making and interface display to avoid errors.
2. Maintenance: this is about the people who maintain the product. The rule of system support engineering is to optimize this process to maximum cost-effectiveness. Either in managing, designing or engineering.
3. Protection: this mainly relates to safety and occupational health, where the hardware should provide maximum protection at all time. The rule of system support engineering is to develop methods to ensure that at all times hardware and liveware are in contact.

3.2 The management level

In this level all the detailed transformation of strategic objectives and vision is carried out. The management level has the same asset classifications as the process level but with different continents to suit the activities of this level. This level acts as the supervisory level of the process level and has a higher overview. All the assets work and interact in the designed working environment to support all their activities. The system support engineering rule is to ensure that the environment is designed and made in a way to support the maximum optimization of the assets' activities. This will be through clearly identifying the types of activities accomplished by assets.

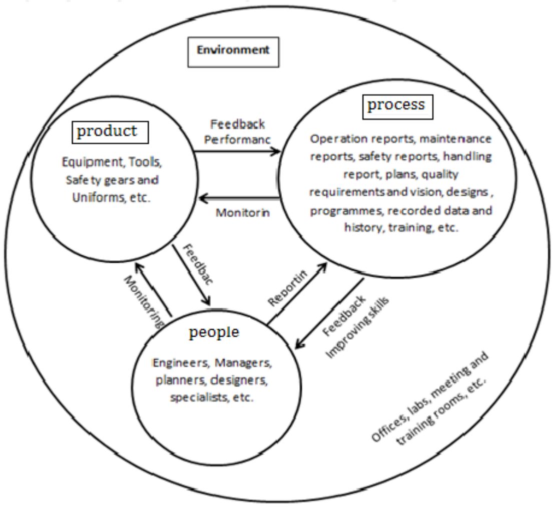

Figure 4. General vision of the management level assets and activities

3.2.1 Product at management level

The product at the management level has the same definition as at the execution level and is divided into three main types:

i. Equipment: this includes all the equipment that is not used in production or maintenance (i.e., computers, phones, printers etc.).
ii. Tools: the tools of the management level are different than in the process level. The tools in this level are all the machines and instruments used for testing, verifying, examine and designing. For example: a dynamic testing machine, an infrared scanner, etc.
iii. Safety gear and uniforms: all the safety equipment and wares, which are required for protection when the job is performed or in case of emergency.

3.2.2 Process at management level

This is basically all nonphysical items. The process in the management level is grouped into:

1. Reports: in this category are all the feedback and the orders of all activities. The deference between this category and the recorded data and history is this one is about the in progress and nonconforming activities. The recorded data and history includes the details of all completed tasks and processes. The main aim of a report is a continuance documention in fast and easy to find during in-progress activities. This will cover the aspects of operation, maintenance, quality, training, supply and design.
2. Plans: under this category are all the tactics of the activities over a specified period of time. These tactics are considered as the source of the detailed schedules in the process level. These planes should cover operation, maintenance, quality, resources, design and training.
3. Quality: this will comprise all the quality necessities and standards. The quality for the management level is not about ensuring inspection only. It also covers benchmarking, performance, management and quality design. It should contain a systemic procedure of quality practice. For example, a training quality system, a management quality system, an HR quality system, etc. It is important to note that the quality in the process level is extracted for the quality of management level. Figure 5 shows a quality management model, which could fit to the SSE model. This model could be implemented through the management and process levels of the SSE model.
4. Designs: all the designs information. The designs can be product designs, process designs, tool designs, system designs or training designs. The designs information should be stored in a unified format. Also, it should have an identity clarification accesses gate where anyone who accesses this information is identified before obtaining the requested design information. The design section should have design instructions and procedures to be used as a reference.
5. Programmes: this category covers all the computer software.
6. Recorded data and history: this has the same description in the management level as in the process level. It is related to all the preformed and finalized tasks. The main difference between data recording and reporting in the management level is that recorded data is dealt with as reference data, not as a feedback or order data. It usually affects long-term or planning decision-making and judgment. It should be structured based on activity relation.

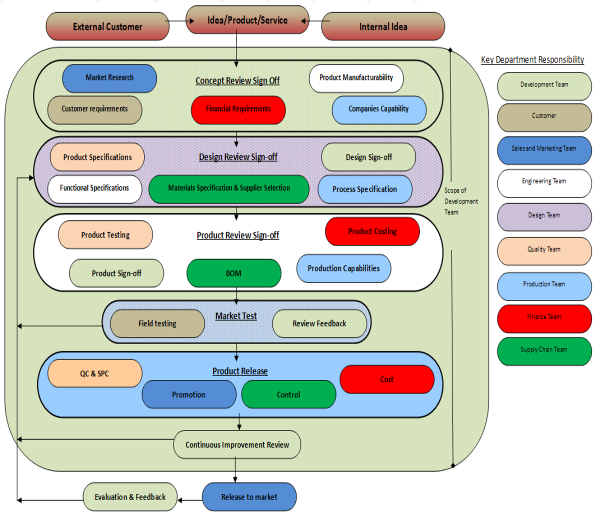

Figure 5. The quality management model

Training: all the education and skills improvement related materials. Figure 6 shows a case study in which operation data of a plant were recorded continuously through active observation.

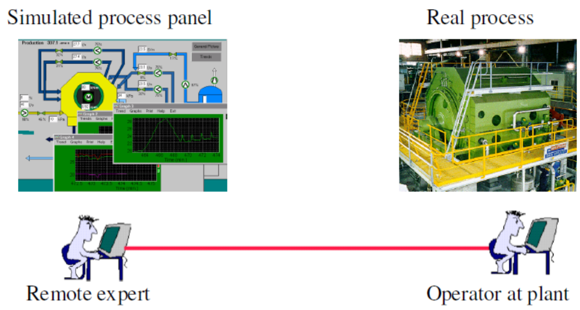

Figure 6. Remote interactions though high tech communication [22]

3.2.3 People at management level

The people in the management level are all the specialists, managers, engineers, etc., but not the executives and directors. The conceptual definition of people is same as the people definition in the process level. People in the management level are responsible for transforming overview strategic decisions, visions and plans to implementable detailed instructive activities and schedules, which can be executed by the process level. Here the management culture will play a big role in people performance and sustainability [23]. The support system for the people in this level should concentrate on supporting the organizational understanding and effective working culture of the people asset. The support system engineering will look at developing a support system, which can identify common themes for the purpose of solving problems and maximizing efficiency and productivity within the people asset. Literature shows [24] that academia has provided theories, which can give a theoretical foundation for development, such as organizational theory studies. Most of the developed theories look at the development, behaviour and psychology of the human. However, none of them actually give any generic framework for people system support in modern complex industry where a long-term solution could be extracted. Therefore, the generic framework of a people system support will be part of the development generic framework of the system support engineering. The development of a generic framework of people system support engineering for the management level will be achieved through employing organizational theories with case studies and by extracting industrial domain knowledge.

3.2.4 The communication between the assets within the environment in management level

The efficiency and effectiveness of the interaction between the assets in the management level has high importance [25], as the management level is the centre processor of an organizational body.

3.2.4.1 Between product – process

The nature of the interaction between the product and the process in the management level has performance feedback and monitoring relations. As the nature of the mentioned relation is quite broad, it will be classified in the following categories:

- Systems Design and implementation: this involves defining and installing the architecture, components, modules, interfaces and data for a system to satisfy specified requirements by using physical design, which is based on identified logic. This physical-logic compensation will build up the system, which has expected inputs and outputs between the hardware and the software. There are some theoretical principles that could be used and employed as a start point, such as General System theory, developed by Von Bertalanffy (1969), Miller's living system theory and Beer's viable systems theory. They give nice hints for system thinking. However, support system engineering is intended to simplify this process as the inputs and outputs are clearly defined through the physical system based on well-established practical logic. Keeping in mind that the developed system in long-term solution is dynamically enough to accommodate with the technology changes and change of demands. System support engineering will employ the knowledge of system engineering and MIT system dynamics.
- Virtual Prototyping [26]: this process is more for visualizing the support system for communication between the hardware and software asset.
- Testing and verification: this could be more for the relation between the people and software or between people and product. But it also can be applied in some cases to the interaction between the product and the process through validating and verifying the support system to support the interface between these two assets. The validation will be based on Design Qualification, Installation Qualification, Operational Qualification and Performance Qualification. The validation can be grouped as follows:
  - Prospective validation: this basically checks that the characteristics of the interests are functioning properly and meet safety standards [27].
  - Concurrent validation [28]: can be applied to the routine check process of system support engineering to validate the alliance between the hardware and the software.
- Quality Function Deployment: QFD could be used to transform an asset's needs into engineering characteristics for the system support engineering, prioritizing each support system characteristic while simultaneously setting development targets for the support system. This will help to identify the asset requirements to serve the customer needs and will explain how the software asset should communicate with the hardware asset. Figure 7 shows the QFD process in SSE.

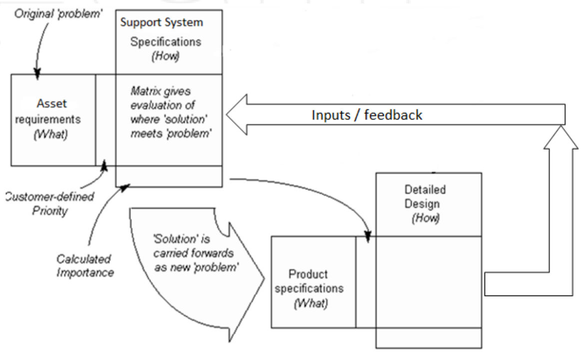

Figure 7. Quality Function Deployment for SSE

- Simulation: in high-risk industries (i.e., power) interaction simulation is a useful tool for examining the interaction between the hardware and software assets. It will give a vision for system support engineering in order to develop the support system for the hardware and software interaction.

- Systems Integration: system support engineering concentrates on systemically supporting the integrated interaction between software and hardware assets to act as a coordinated whole.

3.2.4.2 Between product – people

The relationship between product and people in the management level will have a higher level than a normal human-machine interface. It is more like high skilled knowledge intensive monitoring, operate, service and management. The interaction could be an onshore interaction (both assets are allocated in the same site) or an offshore interaction (remote interaction though high-tech communication).

- Reliability and Risks Analysis: reliability analysis has important links with function analysis, requirements specification, systems design, hardware design, software design, manufacturing, testing, maintenance, transport, storage, spare parts, operations research, human factors, technical documentation, training etc. [29]. Effective reliability engineering requires experience, broad engineering skills and knowledge of many different fields of engineering. To some extent it is the most practical form of support engineering.
- Condition Based Monitoring: from a system support engineering point of view, condition based monitoring is more about optimizing system support maintenance. It plays a critical role in supporting preventative maintenance and product quality control in modern industrial operations [30]. Therefore, it directly impacts industries' efficiency and cost-effectiveness.
- Financial Risks Analysis: financial risk analysis is in regard to cost effective or financially effective choice. This analysis is essentially tells the user if something worth doing and what financial risk is involved. It could be through qualitative and/or quantitative analysis.
- Data Management: usually data management is more common in software-liveware relations. But in some industry the liveware will collect the data directly from the hardware without a software interface. In this case the data collected should have some sort of management format in order to make efficient use of them. The system support engineering should consider developing a systemic methodology of supporting data management. This should be part of the holistic system support.
- Prognostics: in the people-product relationship, this aims to predict the time at which a hardware component will no longer perform its intended function. The support system engineering should include systematic support of the prognostics accuracy.

3.2.4.3 Between people – product

Most of the field studies and industrial visits showed that most of the interaction activities happened between the people and the process in the management level. As the activities wildly vary, they have been categorized into the following activities sets:

1. Decision Support Systems activities: the software providing the liveware with the required information for decision-making. This process would be through identified methodology and logical presentation. This information presentation system is the main interface between these two assets [13]. Based on a wide literature review, decision-making is achieved through a computer-based information system and knowledge-based systems. The computer-based information system is a combination of raw data and recorded documents electronically stored and in some cases accessed. The knowledge-based systems include personal or organizational knowledge with business models functioning jointly or individually to identify and solve a problem or make decisions. The role of support system engineering is to support the decision support system. This could be though supporting the logical system for the decision-making system. System support engineering develops the data collection methodology and presentation, which links the collected data to engineering industrial domain knowledge in a dynamically updated system model.
2. Information Systems: In this level many methods can be used as part of the information system or information exchange system. The information exchange mainly involves transferring information between sources to users. From the support system point of view, it can be informally defined as a system in which liveware performs work using resources to support the production of a product and/or services for customers. The activities of the information system include but are not limited to capturing, transmitting, storing, retrieving, manipulating and displaying information [31]. The information system should give a full meaning to the user and implement the full set of user-friendly interface rules.
3. Decision Theories: the decision theory tries to provide the basis for making optimum choices. In the system support the optimum choice would be the one that delivers long-term sustainable support. From a system support point of view the difficulties of making decisions are because of the complexity of the system. Knowing and framing all the activities is

the key factor that makes decision-making and overviewing all the connected elements easier. This is also where all the possibilities can be listed and connected.

4. Supply Chains, Logistics and Inventory control: a supply chain could include the activities of inventory control and logistics activities. In some cases they are separated into independent systems controlling each of them to ensure the simplicity. The system support engineering will look at them as one supply chain system to be supported because they are highly related and dependent on each other. The support system aims to provide a long-term sustainable support solution for the supply chain activities to increase the efficiency and effectiveness of the supply chain system. This will be through early design of the planned activities based on the generalized framework, which highlights the main activities and the nature of the interaction between them.

3.3 The Enterprise level

The enterprise level contains all the Executives and Directors of an organization. They are the leaders and highest management of the organization. They prepare the vision, strategies and monitor the holistic performance of the organization (Figure 8).

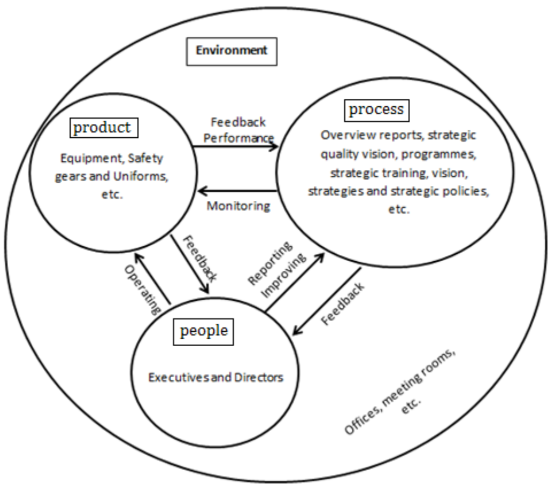

Figure 8. General vision of the enterprise level assets and activities

The assets in the enterprise level are discussed below.

3.3.1 The product at enterprise level

The product in this level is very basic because not much contact with machinery or equipment is required. The main physical items are safety gear and office machines. They are the standard requirements for office and communication proposals. The safety gear is usually used during site visits by the executives for routine inspections. Also, in some cases severance equipment is made available to be used by the directors.

3.3.2 The process at enterprise level

The non-physical items are manly reports, planes and feedback. Also in some cases the members of the executives' team require customized software or computer programs to give them continual updates about certain projects or critical processes. The main software information is classified as follows:

1. Overview reports: reports sent to the enterprise level from the management level. These reports should cover the full picture of what happened or what has been done in a specified period of time. These reports should give an indication to the executives about the overall performance of the units. Therefore, the report format should be designed to present the key performance indicators (KPIs) with a meaningful explanation. The explanation should give a clear idea but should not be too long. The KPIs in the overview report should present and measure the outcomes of a performing unit in a specific time frame. The support system should provide sustainability to the targeted KPI values. Also, the overview reports are exchanged between the executives for further discussion or analysis and in some cases only for awareness.
2. Strategic quality vision: this term is a new term that has started to be heard in a lot in modern industries. This term is a mixture of strategic planning processes, quality concepts and vision. It is basically feeds the strategic planning process with quality concepts to produce a quality vision. The quality vision should highlight where an organization wants to be quality wise. The system support is intended to provide a systemic approach to accomplish the quality vision.
3. Programs: programs in this sense are all the computer software applications used as a tool to make decisions or perform an analysis. Also, in some cases they are used to exchange specific information between assigned users. Moreover, some executives or directors required customized software to monitor specific task(s).
4. Strategic training: the aim of training is to improve people skills to meet the needs to perform an assigned task or mission. As the vision and main strategies are developed in the enterprise level, the training strategy should be designed in the same way to meet the requirements on time. The rule of the system support in this case is ensuring that the development of strategic training is aligned with other major strategy developments.
5. Vision: the vision is developed by the executives team to highlight where organization want to be in the future. The support system targets a systematic approach to fulfil the vision. The support system is designed to support and organize the vision activities. The training vision will be added when the support system is designed.

6. Strategies: the enterprise level is responsible for developing the strategies. The meaning of strategy here is an overview action plan designed to achieve a vision. When preparing the planes, a synopsis systemic support approach is clearly outlined. The combination outcomes should clearly present logical action planes and their support activities in a systemic form.
7. Strategic policies: strategic policy importance comes from the ability to align the organization's vision. It is important to include a support system in the strategic policy to systemically sustain the path to the vision goals. Therefore, the strategic policy should be aligned with the support system policy to avoid any conflicts during operation.

3.3.3 The people at enterprise level

People in the enterprise level contain the executive's team and senior advisors. From the support system point of view their rules are to develop and align vision, strategies and policies with the overall support system outlines. They are the communicators, decision makers and leaders.

4. The information/data structure in System Support Engineering Framework

The framework should provide the necessary categories for the SSE development in order to provide long-term support solutions for in service or planned assets. The framework provides three increasingly detailed views or levels of abstraction from three different perspectives. It allows different people to look at the same system from different perspectives. This creates a holistic view of system support.

First, there is a need to find a way to arrange the information before fitting it to the framework diagram. Then the structure will be used to fit the information in the framework considering the level of detail required. This aims to provide the basic building units for the framework. At this stage there is no final arrangement until the verification is finalized in order to define the SSE categories. However, the detail of the information will increase as it is passed to lower levels. This mean the enterprise level will pass overview order information, such as the development vision, future upgrades and growth, general goals, etc. Then the management will analyse this information, make plans and add the implementation details. After approval from the enterprise level is confirmed, the management will pass the detailed jobs or tasks order information to the shop floor or processing level.

The feedback process is included but is other way around. The shop floor level will provide detailed feedback to the management level. Then the management levels will either take immediate action if required or if the task is completed they will store the detailed information and pass overview feedback to the enterprise level.

The information between the levels will be passed though an information exchange system (Figure 9). Orders will be passed from higher to lower levels to be processed. The feedback will be the other way around. The details will increase as they go down the levels and will be summarized as they go up. The decision of what information needs to be included in the feedback summary or detailed order is based on the goals needed to be achieved for the task and the KPIs for evaluation. Both detailing and overviewing should meet these requirements. The information structure or format is the same as the table shown earlier.

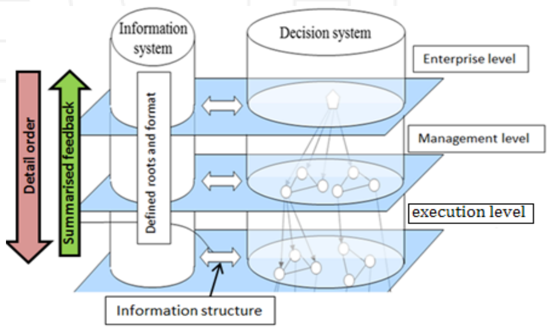

Figure 9. Information exchange system [32]

5. An industry case study

To get a feeling for a real life scenario and to test our design this paper will present an industrial example. For confidential reasons some data are not presented. In this example an Automated Process Control (APC) needs to be installed in a control panel and because of the criticality of this tool it needs to be well supported and maintained without a need to shut down the main control panel. APC is a system/tool that acts automatically to any change of any parameters as it has been reconfigured to so many different scenarios. One of the highest risks is the online testing of such a new system.

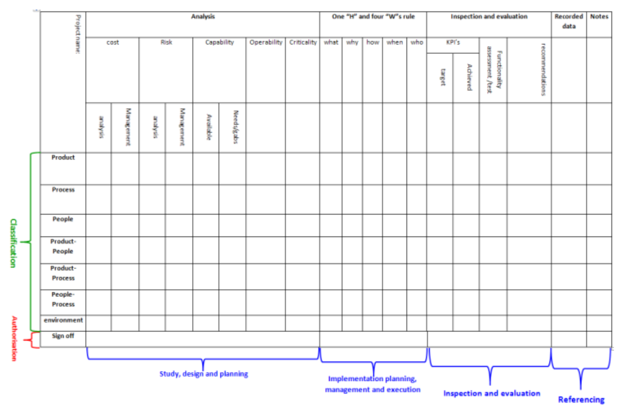

Figure 10. Basic table for information structure

To assist in the data collection process, Table 2 shows the information structure used in the industry visit.

Following this project deeply the researcher highlighted the main needs for the project which include:

1. Details Analysis study: usually a standard study commonly used in the specified industry (e.g., HazOp study, Cause & effects analysis etc.) conducted by a third party expert or certified in house expert. In some other cases (known from other industrial visits) the analysis is done initially by the in house expert and then will be confirmed by the third party expert (consultant).
2. Two servers hardware
3. Software tools required for the project include:

[1] Multivariable Model Predictive Control (SMOC*Pro*)
This tool was developed by Shell Research and has been installed in more than 1000 applications in refinery and petrochemical industries around the world. SMOC*Pro* consists of the following software modules:

- AIDA*Pro* for off-line modelling from plant data
- SMOC*Pro* (Part of PCTP Package) for offline controller design
- ExaSMOC on-line controller

[2] Robust Quality Estimator (RQE*Pro*)
RQE*Pro* is a generic software package for off-line design and on-line implementation of inferential calculations for control, monitoring and information purposes. An inferential calculation is a calculated variable, based on selected available online measurements (temperature, pressure, flow etc.), to predict the current value of an important variable that is not measured on-line, or is measured on-line infrequently, with significant delay or unreliability. In a typical application, RQE*Pro* provides a calculated process value for closed loop control purposes. The RQE*Pro* off-line package is a fully Microsoft Windows XP based graphical package for fast track design and maintenance of inferential calculations.

[3] Controllers Monitoring and Diagnosis (MD*Pro*)

- 4 process engineers trained to be APC specialists' plus all DCS operators.
- Analysis of cost, risk and capability, followed by criticality identification.
- Implementation plan.
- Suitable and consistent Inspection and evaluation strategy and tools.
- Recorded reference data and feedback.
This indicates the following challenges:
- There is a need for a structure, which organizes and covers all the requirements in order to avoid misperception and shortage and minimize reliance on expert judgement.
- The nature of the interaction and interface between the elements in the support system should be clearly identified where it gives a clear meaning to all participants.
- Analysis aims, objectives and outcomes are clearly defined and established. This will be standardly structured to be used for the decision-making process.

Some of the key elements are the order information and feedback information, which are grouped in the same classification in each level (i.e., enterprise, management and process) with different detailed depths. This will provide an easier allocation mechanism for future reference. All the information should be structured in order to provide the basic building unit for the aimed SSE generic framework model.

Several versions of information structuring tables were developed and tested against the literature found and during the case study in order to serve this purpose. The table in Figure 11 showed the best results so far and was implemented by the practitioners in the project. Where they (i.e., the Professionals) thought of it, as a useful tool. Then the table will be used to place information in the framework structure. This will give a unified information arrangement construction where the information category is defined to avoid misunderstanding or confusion. The process of testing the table is shown in Figure 11.

The table contents are:

Columns:

- Project name: the term project has been selected because it is commonly used in the industry. In the industry any development or implementation of a system with particular scope is usually called a "project". The key point is that the project should have the same name, which is identified and clearly known, at all levels. The project name could be:

I. An actual name like: seawater intake unit.
II. Serial numbers based on identify components, for example: *356 SWI*, which could mean Area 3, Section 5, Unit 6 Sea Water Intake.
III. In rare cases the date is used such as July project or Week 32 project.

Analysis: in the industry, the potential for uncontrolled evolution of system support is one of the most significant challenges facing a system support engineer/developer. Practitioners in this field are interested in a comprehensible analysis method. The analysis method or procedure is a key factor and tool [33] for system support evaluation. In system support engineering there are three main analyses that need to be conducted in order to provide a clear picture for the evaluation process of the support system engineering, which are cost, risk and capability.

1. Cost: the cost is divided into two main streams: cost analysis and cost management.
a. Cost analysis in SSE is a bottom-up approach allowing effective cost allocation when disintegrating systems, subsystems and elements to the appropriate level of curiosity. Therefore, it will start from the process level where the cost elements are individually analysed. Then it will be taken to the management level, where the elements will be gathered up to components and subsystems according to the SSE classification. In the enterprise level it will start to analyse the overall cost chunks and final synthesized support system.
b. Cost management is where the cost of the system will be managed. There are well known cost management techniques that could be used and applied [27]. In general, cost management has certain concepts and objectives [34]. The concepts and objectives of systemic cost management equations should be according to the SSE framework classification to align cost analysis with cost management.
2. Risk: according to the ISO 31000 (2009)/ISO Guide 73:2002, risk has been defined as the "effect of uncertainty on objectives". In support system engineering the risk would be the cost and technical and safety uncertainty effects on the support system outcomes and performance. Risk tolerance will depend on the criticality of the support system. Therefore, an appropriate risk analysis and management technique should be developed for the system support engineering framework. This section will talk about concepts of risk analysis and management in the system support engineering framework.
a. Risk analysis: literature shows that a risk analysis fundamentally consists of answering the following questions:
    - What can happen?
    - How likely is it that it will happen?
    - If it does happen, what are the consequences?

  This will require quantitative risk analysis [35] for the system support engineering in order to reach quantified risk values, which could be measured against other parameters. The risk analyses in system support engineering contain cost risk, technical risk and safety.
b. Risk management: in system support engineering risk management should be able to address the following:
- Which risks require management?
- What conditions need to be in place to manage those risks?
- Which of the proposed management conditions will adequately control those risks?
- What is the best practical way to systemically monitor risk?

Figure 11 shows the risk analysis process in SSE

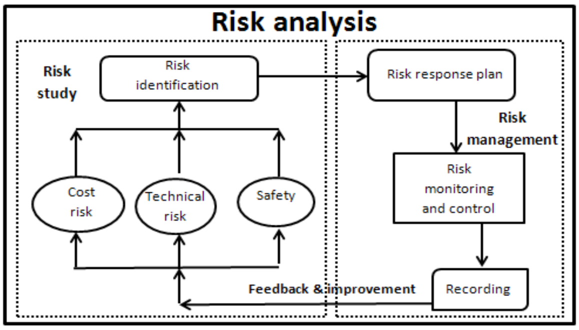

Figure 11. Risk analysis process in SSE

IV. Capability: in the industry this is usually defined as the ability to perform and execute a specified task(s) or course of action and it is often measured against what is available. Then the needs and gaps are defined accordingly. Every industry has its own way of analysing, managing and improving their capability. Therefore, common classification is needed to provide a common platform for capability analysis. This classification should allow each specialist to contribute to the capability analysis process during the support system design. Moreover, it should give a meaning to the other stakeholders of the system support.
    In system support engineering the capability analysis has been divided into two major sections:
a. Availability: the available resources, skills and technologies to enable performing and executing a specified task(s) or course of action effectively and efficiently.
b. Needs or gaps: Are basically the needs and requirements to enable performing and executing a specified task(s) or course of action effectively and efficiently.
3. Operability: is usually defined as the ability to fulfil the operational requirements. Operability analysis of the support system includes all the technical details for operation.
4. Criticality: is the scaling process or system to indicate the importance of the activity or the result. In the industry, frequently the criticality is built on the findings of the previous analysis processes mentioned earlier. Criticality is also known as the importance level signpost of the amount of attention needed to be given to specific task.

The rule of one "H" and four "W"s: this rule provides the initial information about the task. After the task has been classified there is a need to know the following:

1. What exactly is the scope of the task? What needs to be done? This is the answer for the "what" question.
2. Then the reason of the task needs to be identified to evaluate if the task completion has met the requirements. Why this task has been raised?

3. How will the task or activity(s) be clearly outlined? This could include the engineering and technical details. This will provide the relative technical depth desired by each level.
4. The "when" answer needs to indicate the timeframe for the activity(s).
5. Then who will perform or manage the task? This assigns accountability and responsibility for the task completion.

Inspection and evaluation: this section concentrates on two main things: performance and delivery. Performance is basically how good the result is and if there is any improvement that could be added. The delivery answers the question "does it do the required job?"

Referencing: the referencing process is done through proper data recording and note adding. The data should be recoded in a way that makes the tractability an easy and fast process with continual updating. All the observations notes should be add and reviewed as well to highlight any upcoming issues.

6. Conclusion

This paper discussed the development and structure of the SSE framework and how the SSE framework can be applied in providing a systematic modelling approach for system support engineering. The paper presented the finding from the literature review, industrial visits and a case study. The research question was answered by "yes it is possible to have a generic architecture for system support engineering". As a result of the above activities, the authors reached a conclusion that the framework consists of 3 elements in a business environment. As a result of the validation process, the paper also suggested the following recommendations for future research:

- More investigation is needed on the systemic analysis of capability, operability and criticality. The aim of the investigation is standardize the method(s) of the analysis.
- Structure the answers of one "H" and four "W"s rule. The answers should fulfil the requirements of the three levels of the SSE framework.
- More investigation on the inspection and evaluation methodology in the system support engineering framework.

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