AN APPROACH TO INNOVATION IN RISK SYSTEMS

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ABSTRACT

Risk interactions exist between functional and physical elements within a system and its sub-systems in various ”dimensions” such as spatial interaction, information exchange, material transfer, energy exchange etc. The interactions are of a multi-dimensional complexity that cannot be sufficiently interpreted using conventional management tools (PERT, Gantt and CPM methods). Alternative system representation and analysis techniques are proposed, in particular the design structure matrix (DSM), and fuzzy logic thinking to quantify the risk management effort necessary to deal with uncertain and imprecise interactions. A Cement Grinding Plant case study is utilized to elaborate on the risk management methodology.

1. INTRODUCTION AND RESEARCH METHOD

"Innovation is the act of introducing something new" [1]. When companies are competing on the technology "playground" they need to be innovative. By analysis according to Byrd & Brown [1] the "act of introducing", relates to risk taking, and the "new" relates to creativity, and therefore these concepts; creativity and risk taking, in combination, are what innovation is all about. Risk management has become one of the greatest challenges of the 21st century, and one of the key components in innovation and the technology driven industry, intensifying the need for a systematic approach to managing uncertainties [2].

$$\textit{Innovation} = \textit{Creativity} \times \textit{Risk Taking}$$

To think creatively we have to realize "We can't solve problems by using the same kind of thinking we used when we created them" Albert Einstein [3]. Being creative and taking the risk is the only way that innovation can be realized.

Localized and reactive risk management techniques will not be effective in today's globalized high technology industry [4] [5]. The design and development of complex engineering products require the efforts and collaboration of hundreds of participants from diverse backgrounds resulting in complex relationships among both the people involved, functional and physical elements [6]. Risk interactions exist between functional and physical elements within such a system and its sub-systems in various dimensions such as spatial interaction, information interaction etc. The interactions are of a multi-dimensional complexity that cannot be interpreted using the conventional task management tools (for example PERT, Gantt and CPM methods).

The initial research methodology in this paper is of an exploratory nature, to gain insight into, and comprehension of the current status and practices of risk management in the industry as well as the accepted and prescribed methods and practices in the literature. Part of the exploratory phase is to undertake a background literature review to determine the current risk management methodology. The relevance of the existing methods on the technology environment and finally the identification of the current methodology shortcomings and research findings related to the technology driven industry. The second part of the research combines alternative system representation and analysis techniques, in particular the design structure matrix (DSM), and fuzzy logic to quantify the risk management effort necessary to deal with uncertain and imprecise interactions between system elements [7].

2. APPLICATION OF SYSTEMS ENGINEERING IN RISK MANAGEMENT

One of the ways to approach complex problems is to study the underlying structure of the complex system. Systems thinking embraces holism and creativity to handle complexity, change and diversity [8]. In the technology driven industry with its predominantly technically trained people with their logical, realistic and rational approach, it still seems that risk is managed intuitively and largely based on past experiences but risk management within the technology industry is becoming complex due to its multi-dimensional nature.

According to Van Asset [9], decision making becomes complex, when there is not one problem but a tangled web of related problems, when the decision or issue lies across or at the intersection of many disciplines (multi-dimensional), or when the underlying process interacts on different scale levels. Decision making on complex issues is thus decision making in uncertainty, and complexity therefore demands a new “risk logic” and a new form of risk analysis.

The available tools and methods for risk management seem to be not adequate to manage risk in the complex technology driven industry. Furthermore, the perceived need for a systematic approach to risk management is highlighted in these seemingly unstructured current methods of risk management. The approach for risk management in a technology driven industry is unique and similar to the nature of technology, should incorporate a structured and innovative approach.

A common way for understanding a complex system is to make sense of the problem by breaking it apart, therefore analyzing the system through its sub-systems [8] [10] [11] [12]. However, analysis focuses on the elements of a system in isolation and therefore loose relations between the parts. Systemic thinking combines analysis and synthesis [10] (Making sense of things by seeing how they fit together). Figure 1 provides a visualization of systemic thinking in the process plant environment, by breaking a plant into its various sub-systems up to component level, but also indicating how components, areas or units and equipment fit together in the plant.

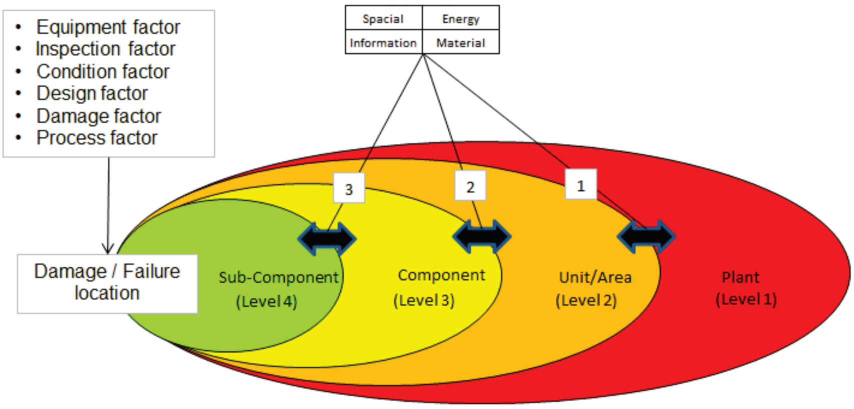


Figure 1: System Visualization (partially adopted from [13])

In a systems approach it is important to always visualize a system as a part of a higher system and also the system itself is composed of lower systems. Most systems are conceptual and depend on perspective. To illustrate this perspective consider the example provided by Paul and Beitz [14] of the combined coupling (consisting of a flexible coupling and a clutch), As “combined coupling” it can be considered as a system which within a machine, or joining two machines, can be considered an assembly. This assembly can be treated as two sub-systems – a “flexible coupling” and a “clutch”, which in turn, can be subdivided into system elements, in this case components. It is also possible to consider the functional relationship where the system “coupling” can be split into the sub-systems “damping” and “clutching”.

3. DESIGN STRUCTURE MATRIX FOR RISK MANAGEMENT

Throughout the engineering disciplines it is common practice for engineers to solve a complex problem by first breaking it into a set of smaller problems that are more easily handled, but the decomposition of complicated systems can create challenges [15]:

- It might be difficult to find the most suitable set of sub-systems.
- It might be difficult to combine the various sub-systems into an overall system.

To overcome these challenges, an overall system functionality or system requirement can be decomposed into sub-system functionalities and sub-system requirements. Similar to the way that designers establish particular systems and particular purposes by decomposing the system, the risks on a system can be decomposed into the sub-risks of the sub-systems. This interaction suggests that a risk on a sub-system will interact with other sub-systems and also contribute to the risk in the total system. With reference to figure 1 this risk-relationship can be visualized by realizing that a failure of one of the two subsystems in either mechanical construction ("flexible coupling" or "clutch") or functionality ("damping" or "clutching") will have an impact on the mechanical construction or functionality of the system ("combined coupling"), in this case the assembly. By quantification of the relationship, the impact can be quantified.

Therefore, a system can be decomposed into its various sub-systems, and by identification and quantification of risks within sub-systems (sub-risk), the system risk can be quantified. The methodology that is used to represent and analyze dependencies and relations between items is known as the Design Structure Matrix (DSM), and was introduced by Steward in 1967 [16] and 1981 [17], these papers are considered the starting point of the DSM field. The major idea of Steward's approach was to handle uncertainty in complex systems by exploring the structure of a problem [18]. Figure 2 illustrates where the DSM field can be used within the risk management process for risk identification, by identifying the relationship between system elements.

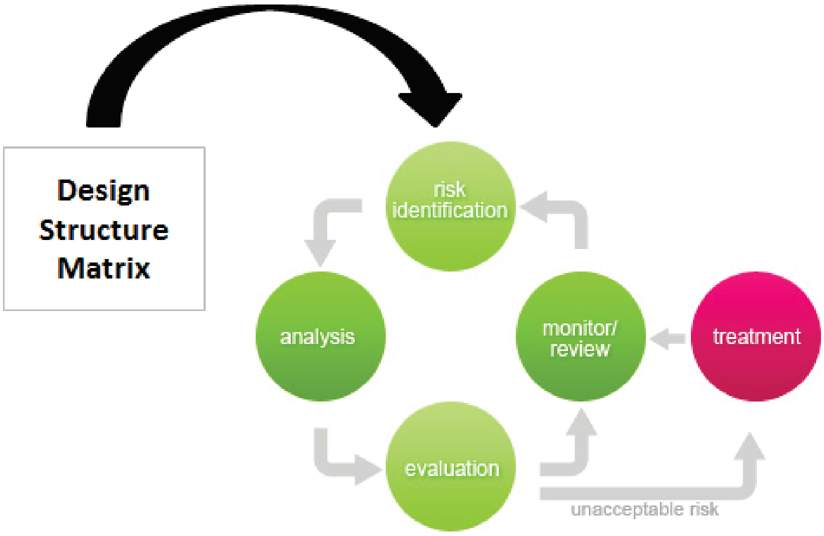


Figure 2: Visualization of Design Structure Matrix within the Risk Management Process (partially adopted from [19])

Similar to the approach of Eppinger and Pimmler [15] where they identify the interactions which may occur between the functional and physical elements, consider 1) associations of physical space and alignment, 2) associations of energy exchange, 3) associations of information (signal & measurement) exchange, and 4) associations of materials (process) exchange.

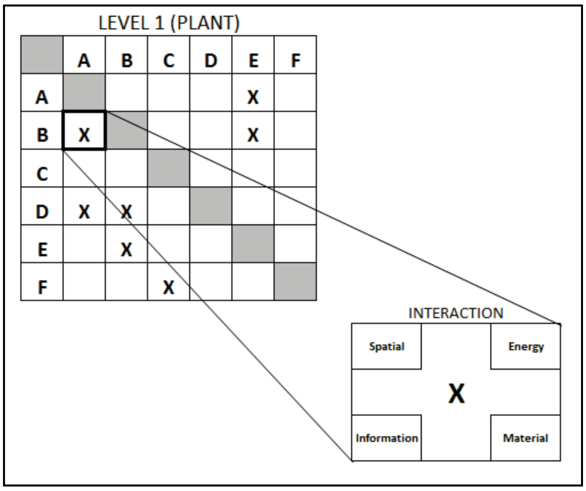
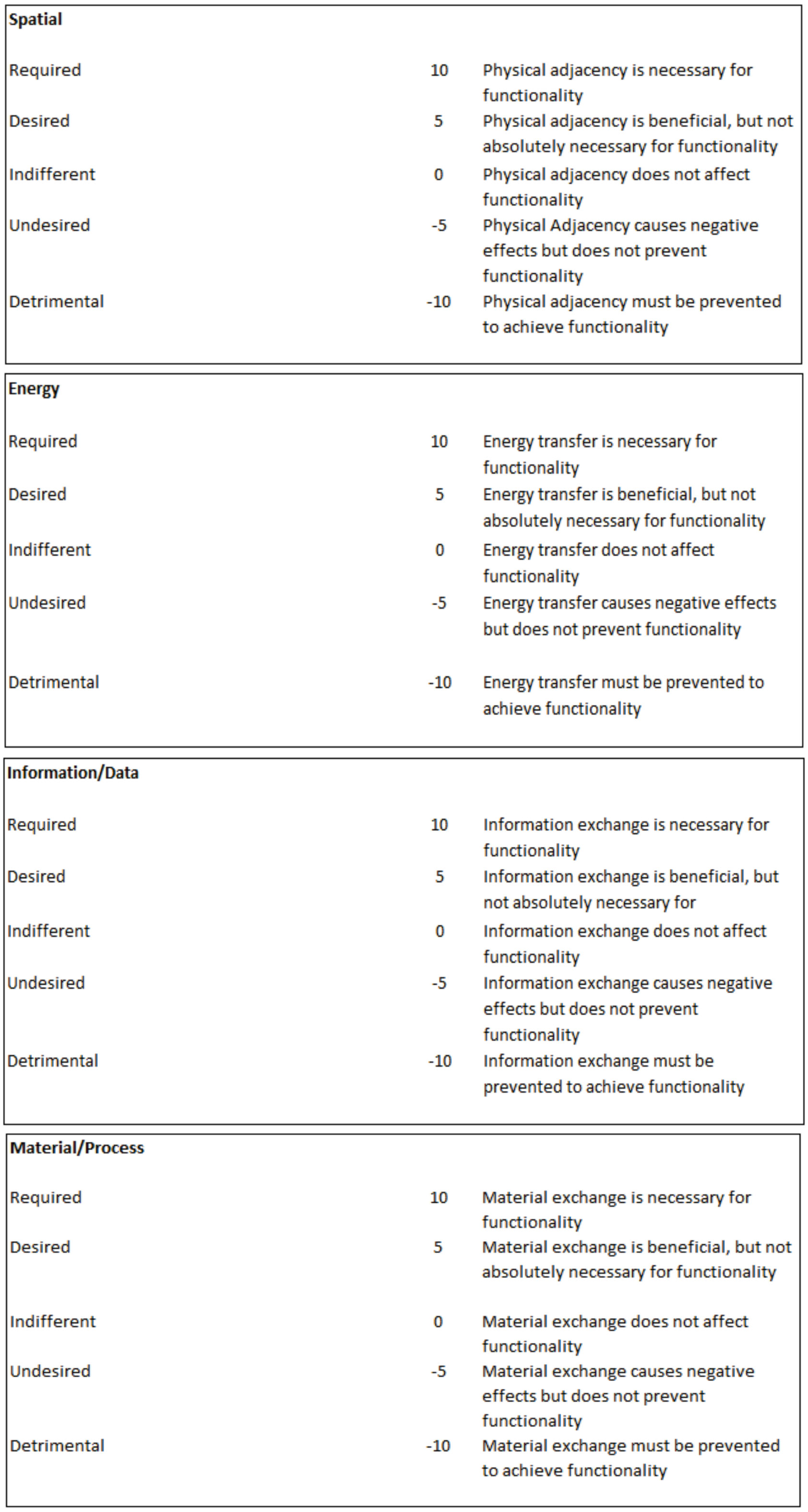


Figure 3: Interaction between elements represented as a vector with 4 scores.

For the purpose of this research, the interaction must be systematically identified to quantify and manage the risk of the complete system. Therefore to identify, quantify and manage the risks areas of a complete system, the risk areas of the various components and elements within the system must be systematically identified and quantified. Referring to figure 3, the four generic interactions are defined as follows:

- Spatial: A spatial-type interaction identifies the needs for adjacency or orientation between elements.
- Energy: An energy-type interaction identifies the needs for energy transfer between two elements.
- Information: An information-type interaction defines the needs for information, signal or measurement exchange between two elements.
- Material: A material-type interaction identifies needs for materials exchange between two elements.

The ranges of interactions are defined in Table 1.



Spatial		
Required	10	Physical adjacency is necessary for functionality
Desired	5	Physical adjacency is beneficial, but not absolutely necessary for functionality
Indifferent	0	Physical adjacency does not affect functionality
Undesired	-5	Physical Adjacency causes negative effects but does not prevent functionality
Detrimental	-10	Physical adjacency must be prevented to achieve functionality
Energy		
Required	10	Energy transfer is necessary for functionality
Desired	5	Energy transfer is beneficial, but not absolutely necessary for functionality
Indifferent	0	Energy transfer does not affect functionality
Undesired	-5	Energy transfer causes negative effects but does not prevent functionality
Detrimental	-10	Energy transfer must be prevented to achieve functionality
Information/Data		
Required	10	Information exchange is necessary for functionality
Desired	5	Information exchange is beneficial, but not absolutely necessary for
Indifferent	0	Information exchange does not affect functionality
Undesired	-5	Information exchange causes negative effects but does not prevent functionality
Detrimental	-10	Information exchange must be prevented to achieve functionality
Material/Process		
Required	10	Material exchange is necessary for functionality
Desired	5	Material exchange is beneficial, but not absolutely necessary for functionality
Indifferent	0	Material exchange does not affect functionality
Undesired	-5	Material exchange causes negative effects but does not prevent functionality
Detrimental	-10	Material exchange must be prevented to achieve functionality

Table 1: General Interaction Quantification Scheme (partially adopted from [15])

4. FUZZY LOGIC FOR RISK MANAGEMENT

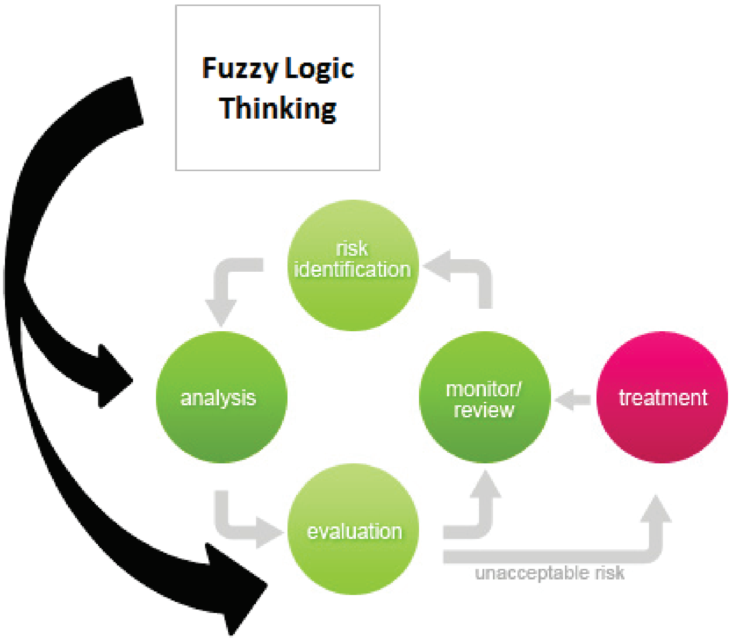
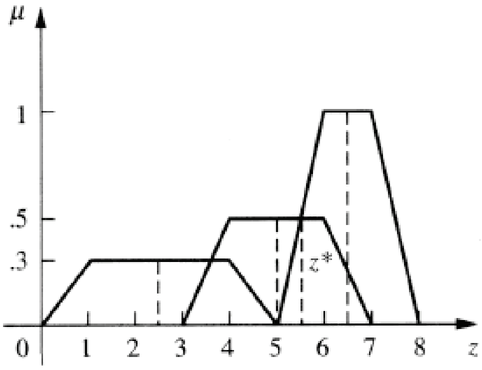


Figure 4: Fuzzy Logic for Risk Management adopted from[19]

The interactions of risk between elements are obtained by interviewing the various system experts. In the case study the system experts were plant and process specialists. However in evaluating this interaction, it is difficult to provide a clear cut definition of what interactions are ”HIGH”, ”MEDIUM” or ”LOW” such vagueness can be addressed in the fuzzy set theory [20] [21] [22]. Fuzzy rules all apply at all times, and they apply in parallel. The fuzzy sets are converted to crisp output values by means of a process called defuzzification [23]. Defuzzification is a process to get a non-fuzzy value that best represents the possibility distribution of an inferred fuzzy control action. [24] The selection of a defuzzification procedure depends on the properties of the application [25] [26] [27]. The weight average defuzzification provides an acceptable accuracy with relatively simple mathematics [28].



$$z^* = \frac{(.3 \times 2.5) + (.5 \times 5) + (1 \times 6.5)}{.3 + .5 + 1} = 5.41 \text{ meters}$$

Figure 5: Weighted Average Defuzzification

5. CASE STUDY

With a focus on the cement grinding section of the cement process and for the purpose of the case study, the following sub-systems of the cement grinding process were defined:

- Clinker Transport
- Additives Transport
- Finished Product Transport
- Recirculation Transport
- Grits Transport
- Mill Drive
- Mill Feeding
- Separator (and Cylones)
- System Filter
- Hot Fuel Oil Supply
- Hot Gas Generator
- Mill Hydraulic
- Compressed Air / Cooling Water

The relationship and interactions between elements are obtained by interviewing the various system experts. In the case study a small group consisting of 5 plant experts were asked to completed a survey and provide a quantification of the interaction between plant components based on their experience and the plant process. After data collection and mapping of the interdependencies into the design structure matrix on the spatial, energy, material and information levels, fuzzy logic is used to determine the overall interdependency between elements by applying the fuzzy rules chosen. A simplified version of the fuzzy controller is presented below.

Chosen Fuzzy rules:

- Rule 1 : IF (Spatial is required) OR (Information is required) OR (Energy is required) OR (Material is required) THEN RiskManagementEffort = HIGH
- Rule 2 : IF (Spatial is desired) OR (Energy is desired) OR (Information is desired) OR (Material is desired) THEN RiskManagementEffort = MEDIUM
- Rule 3 : IF (Spatial is indifferent) OR (Energy is indifferent) OR (Information is indifferent) OR (Material is indifferent) THEN RiskManagementEffort = LOW

Representation of values in the fuzzy controller for a specific interaction:
(Spatial, Information, Material, Energy) = (5,7,2,1)

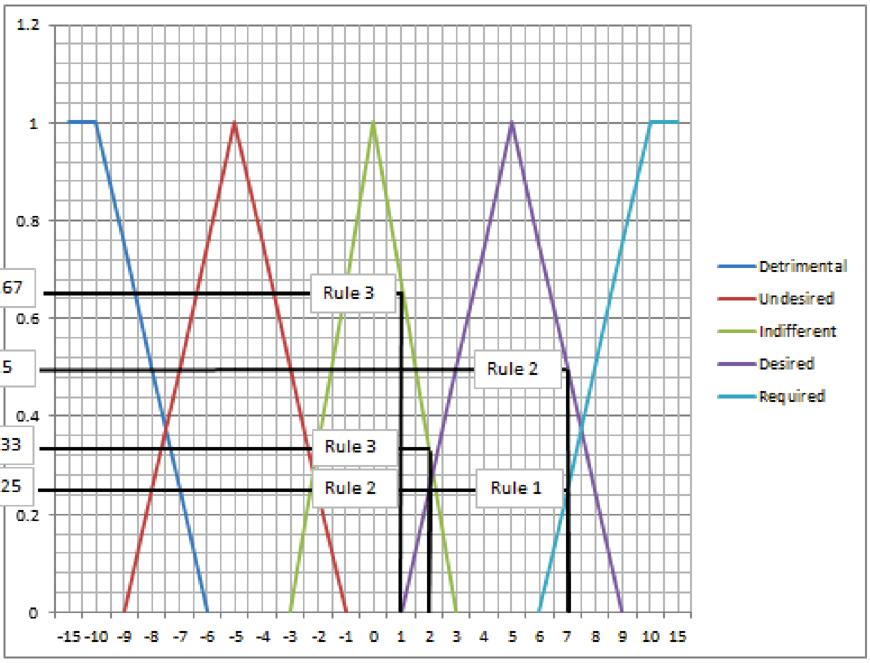


Figure 6: Application of rules in the fuzzy controller

In figure 6 the evaluation of Rule 1, Rule 2 and Rule 3 provides the following:

- Rule 1 Input is MAX(0,0.25,0,0,0) = 0.25 and Output is 6 (High)
- Rule 2 Input is MAX(0,0.25,0,0,0,0,0.5,0,0) = 0.5 and Output is 4 (Medium)
- Rule 3 Input is MAX(0,0,0,0,0.667,0.333,0) = 0.667 and Output is 2 (Low)

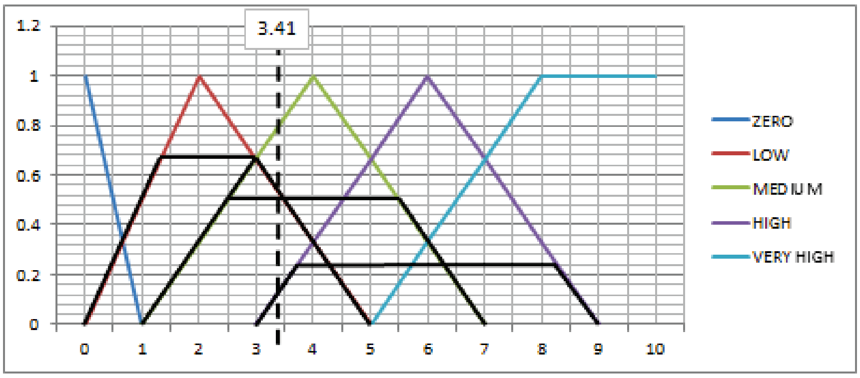


Figure 7: Fuzzy controller output (Risk Effort)

From the weighted average equation:

Risk Management Effort = ((0.25 x 6) + (0.5 x 4) + (0.667 x 2)) / (0.25 + 0.5 + 0.667) = 3.41

From figure 7, the risk management effort required to manage the risk between two system components with (Spatial, Information, Material, Energy) = (5,7,2,1) is 3.41, and viewed as a medium risk. The four separate design structure matrixes (containing the components for spatial, information, material and energy) can be represented by one matrix containing the fuzzy controller output values. The value 3.41 obtained in the example represents the interaction between the Hot Gas Generator and the System Filter, the value is rounded to 3 in figure 8.

	Clinker Transport	Additives Transport	Finished Product Transport	Recirculation Transport	Grits Transport	Mill Drive	Mill Feeding	Separator	System Filter	Hot Fuel Oil Supply	Hot Gas Generator	Mill Hydraulic	Compressed Air / Cooling water
Clinker Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Additives Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Finished Product Transport	0	0	0	6	0	0	0	6	0	0	0	0	0
Reciculation Transport	0	0	6	0	6	8	0	8	6	0	0	0	0
Grits Transport	0	0	0	5	0	0	0	5	0	0	0	0	0
Mill Drive	0	0	0	4	0	0	6	5	5	0	0	4	0
Mill Feeding	0	0	0	0	0	7	0	0	0	0	0	0	0
Separator	0	0	5	5	5	5	0	0	0	0	0	0	0
System Filter	0	0	0	4	0	5	0	0	0	0	3	0	0
Hot Fuel Oil Supply	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Gas Generator	0	0	0	0	0	0	0	0	3	0	0	0	0
Mill Hydraulic	0	0	0	0	0	5	0	0	0	0	0	0	4
Compressed Air / Cooling wate	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8: Fuzzy controller output values represented in DSM

Once the output values are presented the new goal becomes finding subsets of DSM elements (i.e., clusters or modules) that are mutually exclusive or minimally interacting. This process is referred to as clustering [29]. In other words, clusters contain most, if not all, of the interactions internally and the interactions or links between separate clusters is eliminated or minimized [30]. By clustering system elements together based on their interdependency, risk areas can be clustered together forming focal points for risk management effort. The low risk areas are grouped in the upper left corner of the DSM presented in figure 9, while medium to high risk areas are grouped together in the lower right corner of the DSM. The focus areas are now clustered together based on the high dependency of their interaction, and the graphical representation of the DSM in figure 10 visually highlights the focal points for risk management effort.

	Clinker Transport	Additives Transport	Hot Fuel Oil Supply	Compressed Air / Cooling water	Mill Hydraulic	System Filter	Hot Gas Generator	Mill Feeding	Mill Drive	Grits Transport	Recirculation Transport	Separator	Finished Product Transport
Clinker Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Additives Transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Fuel Oil Supply	0	0	0	0	0	0	0	0	0	0	0	0	0
Compressed Air / Cooling water	0	0	0	0	0	0	0	0	0	0	0	0	0
Mill Hydraulic	0	0	0	4	0	0	0	0	5	0	0	0	0
System Filter	0	0	0	0	0	0	3	0	5	0	4	0	0
Hot Gas Generator	0	0	0	0	0	3	0	0	0	0	0	0	0
Mill Feeding	0	0	0	0	0	0	0	0	7	0	0	0	0
Mill Drive	0	0	0	0	4	5	0	4	0	0	4	6	0
Grits Transport	0	0	0	0	0	0	0	0	0	0	5	5	0
Reciculation Transport	0	0	0	0	0	6	0	0	8	6	0	8	6
Separator	0	0	0	0	0	0	0	0	5	5	5	0	5
Finished Product Transport	0	0	0	0	0	0	0	0	0	0	6	6	0

Figure 9: Partitioned representation of risk management effort DSM

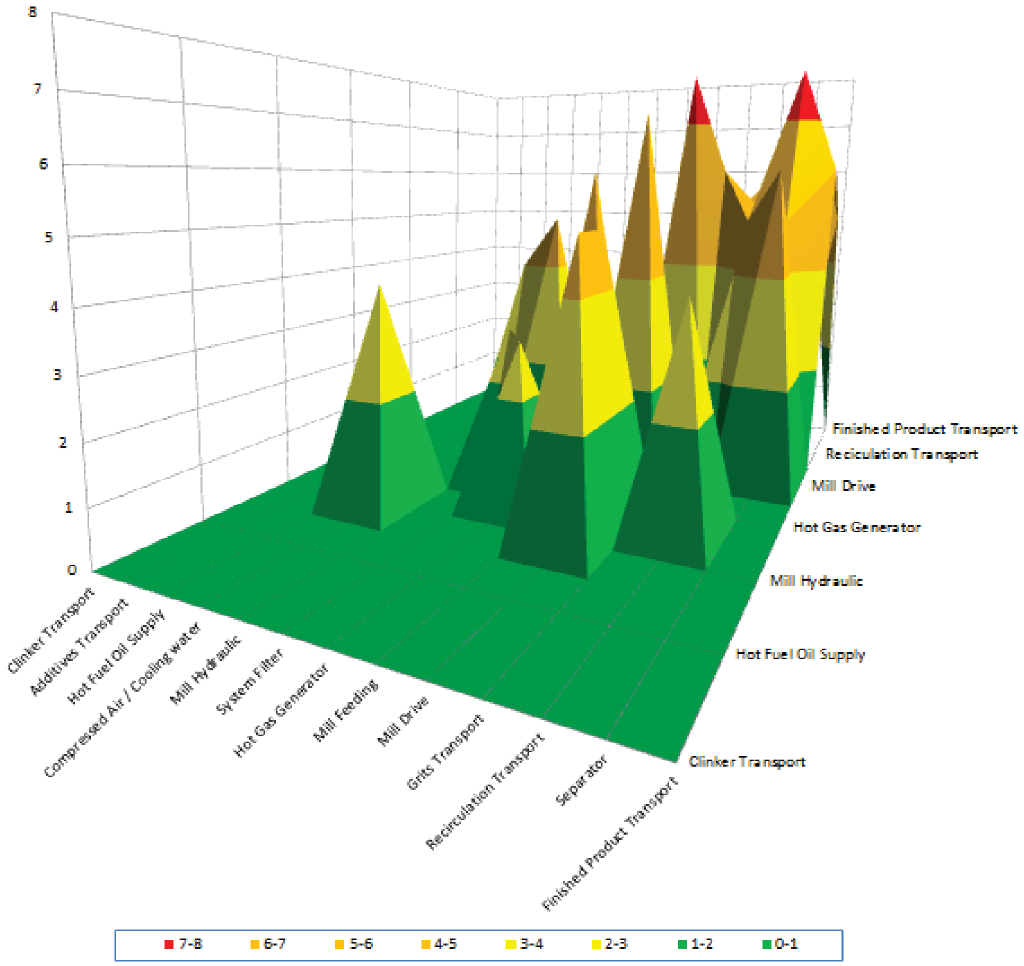


Figure 10: Graphical representation/highlight of risk efforts within the plant.

6. CONCLUSION

The application of the design structure matrix (DSM) as an alternative to the conventional management tools (PERT, Gantt, CPM methods etc.) provides a method to represent multi-dimensional interactions. Fuzzy logic thinking lends itself to quantify the multi-dimensional interactions, and by introduction of fuzzy rules, these multi-dimensional interactions can be simplified and represented by a one-dimensional design structure matrix. The DSM can be further manipulated by using DSM tools such as clustering to group system elements and form focal points for risk management effort.

An introduction to the application of the DSM field as an alternative approach to classical risk management techniques for managing complex systems was investigated. By simply constructing and analyzing the DSM, a visual overview of the system is provided and already improves understanding and visualization of the system complexity.

Therefore, a system can be decomposed into its various sub systems, and by identification and quantification of risks within sub-systems (sub-risk) using a design structure matrix combined with fuzzy logic thinking, the system risks can be quantified. The case study illustrated the possibility of systemic risk management - making sense of risk by seeing how components interact.

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