Modelling of Risk Analysis in Production System

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Abstract:
Production system may be defined as "The procedure, methods or arrangement which includes all functions required to gather the inputs, process or reprocess the inputs, and deliver the finished output". Industries are also faced with different challenges due to the increasing complexity of their own production processes. Owing to the complex nature of production system because of its interface between organizations, technologies and tacit knowledge of employees, it is very difficult to analyse the inter-relationship among the various risks. Interpretive structural modelling (ISM) is a well-established methodology for identifying relationships among specific items, which define a problem or an issue. In this study, inter relationships among various risks like coordination risk, disruption risk quality risk etc. are established and categorized eight risks in four categories to focus on most influential risks among them.

Keywords: Production system, Risk, Interpretive Structural Modelling, Interrelation of Risk

1. Introduction
Production system is defined as "The procedure, methods or arrangement which includes all functions required to gather the inputs, process or reprocess the inputs, and produce finished product" or it can also be defined as the method of converting input to output. Production system utilizes infrastructure, funds, materials and labour to produce finished product. Production system has three main components i.e., Input, Conversion Process and Output [21].

The concept of risk is measured in terms of the probability of occurrence and the severity of loss or gain [85]. Risks is raised by the human’s effort. Rewarding those who easily understand all processes and systems and take immediate action to remove risks [84]. Production risks can be defined as deviation of target from planned cycle [23]. The cause of risk occurs with a certain possibility. The consequences of risk can be seen on an industries output. Delay in material ordered and quality defects represent production risks. Risk in production system is a negative deviation from target cycle while manufacturing a product [23]. We consider that there are many risks in the production system and there are also many challenges to create strategies, controls, and regulations designed to manage risks while looking for to attain production target [84].

Industries are faced many challenges due to the increasing difficulty in production system. Increasing automated production system can improve production efficiency but can also generate new risks or problems for the industries production process [51]. This type of risks must be considered firstly and minimize their impact on target output. Such risks consider during the planning stages of the production system. However, those risks that obtained during short-term production phases can be taken within the related production planning phases [26].
Advantages of reducing risk from production system are:
1. It helps to increase in production rate.
2. It helps to decrease production time and money.
3. It decreases wastage of raw material.
4. It reduces the problems in supply chain network.
5. It reduces the overall cost of production system.

Disadvantages of risks are:
1. Risk effect overall profit of the industry and which will affect input choice Decisions [56].
2. Less production rate is not only raised due to weak management work but also due to risk in production system [15].
3. The productivity and profitability of the industry are affected by the risk in large production system [54].
4. Shutdown of production sites is due to political or geographical risk [66].

According to above literature, many researchers have been created various number of models, methods to study the impact of various risks on production system. In this research relationship among several types of production risks is found. Due to the complex nature of production system, to analyse the inter-relationship among the various risks is very difficult [9].

In this research, various methods such as FBN, TNT, FMEA are used to study the interrelationships (see, e.g., [74]; [82]; [68]).

Interpretive structural modelling (ISM) is used by the author. It is a well-established methodology for identifying relationships among items.

The objective of this work is to identify the driver or influential risks in production system among all analysed risks which are enhance risk capacity of other risk also.

2. ISM
ISM is an interactive learning process. From this method we can define how items or risks are related. According to relationship among items, an overall structure is taken out from the set of items. After that it is modelling and finally overall structure is represented in a diagraph model [71]. It is used to identify interrelationships among various parameters which describe an issue or a problem [34].

In ISM a set of dissimilar directly and indirectly related variables are arranged into a systemic model. The existence of these variable makes the structure of system more complex. It then becomes difficult to deal with this type of system. Hence, a methodology is required which helps to identify a structure within a system [43].

Four symbols are used to represent the relationship between variables (p and q) are V, A, X, O. This data is indicated in the arrangement of binary matrix called initial reachability matrix (IRM). If an element p reaches element q, then the entry is 1 and if element p does not reach element q, then entry is 0 [43].

3. Identification of Risks in Production system
There are many risks which affect performance of production system. Few risks with literature support are discussed as follows:
| S. No. | Name of risk          | Definition                                                                                   | References                                                                 |
|-------|-----------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1.    | Production risk       | Production risks is defined as deviations from initially set targets of production arising from turbulences in the production system. | (Kumbhakar, 2002), (Picazo- Tadeo & Wall, 2011), (Ogundari & Akinbogun, 2010), (McLellan & Corder, 2013), (Antle, 1983) |
| 2.    | Organisational risk   | This type of risk is at the top level of an organization that includes regulatory, material strategic, legal, reputational, security etc. | (Horlick-jones et al., 2001), (Macias-Garza & Heeks, 2006), (Kerstin et al., 2014) (Fadun, 2014), (Huber & Rothstein., 2013) |
| 3.    | Schedule risk         | In schedule risk project takes longer time than fixed scheduled.                              | (Wang, 2002), (Kim et al., 2009), (Wang & Lin, 2009), (Finke et al., 2010), (Hu et al., 2016) |
| 4.    | Quality risk          | Quality risk is the risk in which losses due to quality of product that fails to meet product quality according to quality target. | (Gray et al., 2011), (Kaya & Ozer, 2009), (Kei Tse et al., 2011), (Tse & Tan, 2012), (Reich & Paz, 2008) |
| 5.    | Political risk        | Political risk is the risk that originate with different areas with their different oriented political systems. | (Kumar et al., 2014), (strausz, 2017), (Prasad & Babbar, 2000), (Kesternich & Schnitzer, 2010), (Jensen & Johnston, 2011), (Chauhan et al., 2015), (Hansen et al., 2018) |
| 6.    | Operational risk      | Operational risk is obtained where facilities is not delivered as expected or failure in systems or infrastructure or technology. | (Aron & Singh, 2005), (Quelin & Duhamel, 2003), (Aron et al., 2005), (Jarrow et al., 2010), (Moosa, 2011) |
| 7.    | Coordination risk     | Coordination risk exists when there is a miscommunication between employees of                | (Croson et al., 2014), (Dorward et al.,) |
To manufacture the product with some error in design and quality of product arising from turbulences in the production system is known as production risk [46]. The estimation of production risks can be associated with material flow development or the development of the Overall Equipment Effectiveness (OEE) [40]. The characteristics of energy flexibility measures is also affected by production risk [70]. Production risks is defined as deviations from initially set targets of production arising from turbulences in the production system. In industrial production process increasing complexity enhance the difficulty of the cause-and-effect relationships of industrial risks [72]. Organizational risk can be defined as the consequences of problem involving technical systems or in management of industry [49]. The problems of an organization’s risk are mainly determined by its members’ decision and actions. Organisational risk management works on evaluating and control the physical and environmental risks of corporate activities, managing financial and business risks. Organisational risk such as roles and responsibilities of all people involved in production system [65]. Those organisational risks which are associated with financial ones, legal liability, industrial relations are appeared stronger than the risks associated with physical hazards [27]. Organisational risk tendency directly disturbs the decision-making behaviour of teams, with directly impacts on the current success of the organisation [25]. Schedule risk is defined as delay due to order processing, manufacturing and logistics [67]. The idea of schedule risk is proposed to estimate the schedule performance of production system. The idea of schedule risk is proposed as the performance measure to schedule the uncertain product development project. A stock out is the main cause of risk effecting the completion of an order within a given time. Therefore, the risk of tardiness or delay with respect to the given time can be sort out with the customer [59].

Figure 1 shows the risk involve in production and cause & effect along with their relationship

![Figure 1. Cause and effect chain of the risk in production [72]](image)

Table 1

| No. | Type of Risk | Description | References |
|-----|--------------|-------------|------------|
| 8.  | Disruption risk | A disruption risk is referred to as the main disruptions caused by natural disasters such as earthquakes, floods and manmade disaster such as labour strikes, terrorist attack. | (Yu et al., 2009), (Kleindorfer & Saad, 2005), (Tomlin, 2006), (Sawik, 2016), (Li et al, 2011) |
scheduling decisions. The cause of stock out risk is insufficient inventory. This type of risk is linked to availability of inventory items to mitigate the risk of schedule tardiness or delay [59].

Quality risk is defined as the tendency of production process to fail to achieve good quality of product. Quality risk is obtained when a product dispatched from a given process will not perform as proposed due to problems in production system or in technology and machine [22]. Working with low quality risk is necessary because complete testing of final product is either impossible or costly. Therefore, it is compulsory to both operating actions and processes that produce defect-free products [12]. Raw materials, manufacturing processes, or logistics operations are the cause of quality risk in production system [78].

Political risk is very unstable and it is very difficult to observe, that’s why it ignored. Sovereign risk, geographical risk and exchange rate risk are the categories of political risk. Political risk related with different areas with their different oriented political systems [4]. In political risk the policies of a country are uncooperative of organisations and harmfully affect an organisations profit [14;76]. In political risk national governments has limited action [42], mainly involving confiscation, currency inconvertibility, contract rejection, discriminatory taxation, prohibition, nationalisation [28]. Country’s policies are the main cause of political risk that lead to lower returns through restrictions on return of profits, price controls [62]. Political risks are also associated with quality of bureaucracy, intellectual property protection, corruption, organised labour strike, host government stability and internal conflict etc [24]. It is necessary to recognise the definition of political risk because risk originates from various political processes variables or on-going change [19]. On-going change means continuous activities such as legislation, monetary policy, macroeconomic management which affect the total industrial work [9;11].

Operational risk is divided into two types:
(i) the risk is due to loss in industries operating system
(ii) the risk is due to activity costs.
These two types of operational risks create losses with different economic characteristics [31]. Operational risk is associated with supply-demand coordination, inadequate or failed processes, obstacle in machine or technology and human error [7]. Quality and delivery problems are the examples of operational risk. Operational risk is more controllable than any other risk [8]. Operational risk is also associated with operational actions, disrupting material, information flow within whole production system [47].

Coordination risk exists when decision taken by individuals may contribute to a collective result and the decision rules followed by individual may be not known [13]. Coordination risk exist when there is a miscommunication among employees of organisation. A coordination risk exists when there is necessary to coordinate about the process system but organization may not be able to achieve [6]. Contributing factor of coordination risk are demand and supply uncertainty, such uncertainty may arise from external sources. Inter-organisational information systems (IOS) is a system which is used within supply chain management (SCM) to improve business processes and to enable better working relations between two organisations [83]. Coordination risk may arise from two factors:
(1) A lack of common information about the further process.
(2) A lack of trust between two organisations [13].

Disruption risk is associated with two different sources:
1. Operational Possibilities
   This include equipment’s fault and system failures. For e.g. A grid blackout in the northeast region of the USA in August 14, 2003.
2. Natural Hazards- Earthquakes, Storms and Hurricanes
A sequence of hurricanes in Florida in 2004, and the Kobe earthquake in Japan in 1995 which affect massive distribution disruptions in Florida and large losses to industries [41]. The disruptions in the electronics supply chains due to the earthquake in East Japan in March 11, 2011 where many component manufacturers were affected, resulted in massive losses of many Japanese industries [55]. Disruption risks is reduced by minimizing the potential worst-case cost. Increasingly from time-to-time production system become vulnerable to various kinds of unpredictable disruptions which cause huge uncertainties to production system. Any disruption can have a dramatic impact on the entire production system [63].

4. ISM Methodology

The steps which are used for the development of ISM model are discussed below:

4.1. Contextual relationship establishment among risks

In this research 8 risks are identified. To analyse the risks, a relationship of ‘reaches to’ form is used. It means one risk influence another risk. From this method, a contextual relationship is obtained.

Structural self-interaction matrix is developed by using four symbols which are used to indicate the relationship between the risks (p and q) [5].

1. V is denoted from risk p to risk q (means risk p influence risk q).
2. A is denoted from risk q to risk p (means risk q influence risk p).
3. X is denoted for both direction relations (means risks p and q influence each other).
4. O is denoted for no relation between the risks (means risks p and q are unrelated) [5].

4.2. SSIM

On the basis of contextual relationship between the risks, the SSIM is developed. The SSIM was finalized and is presented in Table. 2.

| S. No. | Risks                      | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------|----------------------------|---|---|---|---|---|---|---|
| 1     | Production risk            | A | X | A | X | A | A | A |
| 2     | Organisational risk        |   | V | O | A | V | X | A |
| 3     | Schedule risk              |   | O | A | X | O | A |   |
| 4     | Quality risk               |   | O | A | O | A |   |   |
| 5     | Political risk             |   | V | O | V |   |   |   |
| 6     | Operational risk           |   | A | A |   |   |   |   |
| 7     | Coordination risk          |   | O |   |   |   |   |   |
| 8     | Disruption risk            |   |   |   |   |   |   |   |

4.3. IRM

IRM is obtained by converting SSIM into binary matrix. In this matrix V, A, X and O are substituted with 1 and 0 and is represented in Table 3. The rule for this is given below:

1. If (p, q) entry in the SSIM is V, then (p, q) entry in the IRM will become 1 and (q, p) entry will become 0.
2. If (p, q) entry in the SSIM is A, then (p, q) entry in the IRM will become 0 and (q, p) entry will become 1.
3. If (p, q) entry in the SSIM is X, then (p, q) entry in the IRM will become 1 and (q, p) entry will also become 1.

4. If (p, q) entry in the SSIM is O, then (p, q) entry in the IRM will become 0 and (q, p) entry will also become 0 [75].

| S.No. | Risks            | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|------------------|---|---|---|---|---|---|---|---|
| 1    | Production risk  | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 2    | Organisational risk | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| 3    | Schedule risk    | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 4    | Quality risk     | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 5    | Political risk   | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 |
| 6    | Operational risk | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 7    | Coordination risk | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 8    | Disruption risk  | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |

Table 3. IRM

4.4. Final reachability matrix (FRM)
The IRM is converted into FRM and is presented in Table 4. It used transitivity concept. Table 5. shows FRM with driving power and dependence.

| S.No. | Risks            | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|------------------|---|---|---|---|---|---|---|---|
| 1    | Production risk  | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 2    | Organisational risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| 3    | Schedule risk    | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 4    | Quality risk     | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 5    | Political risk   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6    | Operational risk | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 7    | Coordination risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| 8    | Disruption risk  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |

Table 4. FRM

| S.No. | Risks            | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------|------------------|---|---|---|---|---|---|---|---|
| 1    | Production risk  | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 2    | Organisational risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| 3    | Schedule risk    | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 4    | Quality risk     | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 5    | Political risk   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6    | Operational risk | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 7    | Coordination risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 |
| 8    | Disruption risk  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |

Table 5. FRM with driving power and dependence

| S.No. | Risks            | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Driving power |
|------|------------------|---|---|---|---|---|---|---|---|---------------|
| 1    | Production risk  | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 4             |
| 2    | Organisational risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 6             |
| 3    | Schedule risk    | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 4             |
| 4    | Quality risk     | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 4             |
| 5    | Political risk   | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8             |
| 6    | Operational risk | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 4             |
| 7    | Coordination risk | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 6             |
| 8    | Disruption risk  | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7             |

Dependence 8 4 8 8 1 8 4 2
4.5. Partitioning the FRM

FRM derives the antecedent sets and reachability set. The antecedent set contains element itself and the other element which may impact it. Whereas, the reachability set contains element itself and the other element which it may impact. Then derived the intersection of these sets. Those elements whose reachability and the intersection sets are same indicate at highest level in the ISM hierarchy. After the identification of highest elements, they are eliminated from the table. Then by the same process find out the elements in the next level. In this case, the level identification process for the 8 risks is accomplished in four iterations and is shown in Tables 6 - 9 [43].

| Table 6: First iteration |
|---|
| Risks | Antecedent | Reachability | Intersection | Level |
| 1     | 1,2,3,4,5,6,7,8 | 1,3,4,6 | 1,3,4,6 | I |
| 2     | 2,5,7,8 | 1,2,3,4,6,7 | 2,7 | |
| 3     | 1,2,3,4,5,6,7,8 | 1,3,4,6 | 1,3,4,6 | I |
| 4     | 1,2,3,4,5,6,7,8 | 1,3,4,6 | 1,3,4,6 | I |
| 5     | 5 | 1,2,3,4,5,6,7,8 | 5 | |
| 6     | 1,2,3,4,5,6,7,8 | 1,3,4,6 | 1,3,4,6 | I |
| 7     | 2,5,7,8 | 1,2,3,4,6,7 | 2,7 | |
| 8     | 5,8 | 1,2,3,4,6,7,8 | 8 | |

| Table 7: Second iteration |
|---|
| Risks | Antecedent | Reachability | Intersection | Level |
| 2     | 2,7 | 2,7 | 2,7 | II |
| 5     | 5 | 2,5,7,8 | 5 | |
| 7     | 2,5,7,8 | 2,7 | 2,7 | II |
| 8     | 5,8 | 2,7,8 | 8 | |

| Table 8: Third iteration |
|---|
| Risks | Antecedent | Reachability | Intersection | Level |
| 5     | 5 | 5,8 | 5 | |
| 8     | 5,8 | 8 | 8 | III |

| Table 9: Fourth iteration |
|---|
| Risks | Antecedent | Reachability | Intersection | Level |
| 5     | 5 | 5 | 5 | IV |

| Table 10: ISM based level of risk |
|---|
| S.No. | Risks       | Level |
| 1     | Production risk | I |
| 2     | Organisational risk | II |
| 3     | Schedule risk | I |
| 4     | Quality risk | I |
4.6 Conical matrix
In FRM clubbing risk across the rows and columns forms Conical matrix. Summing the number of ones in the row’s forms driving power and summing the number of ones in the columns forms dependence [43].

| Risk (number of risk) | 1 | 3 | 4 | 6 | 2 | 7 | 8 | 5 | Driving power |
|-----------------------|---|---|---|---|---|---|---|---|--------------|
| Production risk (1)   | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4            |
| Schedule risk (3)     | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4            |
| Quality risk (4)      | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4            |
| Operational risk (6)  | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4            |
| Organisational risk (2)| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6            |
| Coordination risk (7) | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 6            |
| Disruption risk (8)   | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 7            |
| Political risk (5)    | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8            |
| Dependence            | 8 | 8 | 8 | 8 | 4 | 4 | 2 | 1 |              |

4.7 Diagraph
According to conical matrix, the initial diagraph including transitive links is found. It is created by nodes and lines of edges [60]. A final diagraph is developed after eliminating the indirect link (figure 2). The relationship between the risk q and p is represent by an arrow from risk p to q.

Figure 2: The level of production system risk is shown by diagraph

4.8 ISM model development
After substituting the nodes with name of risks a diagraph is converted into an ISM model as shown in Figure 3.

4.9 MICMAC analysis

Matrice d’Impacts croises-multiplication appliqu´ean classment (cross-impact matrix multiplication applied to classification) is referred to as MICMAC. The aim of MICMAC analysis is to analyse the driving power and dependence power of factors. The principle of MICMAC is based on multiplication properties of matrices [69]. On the basis of their driving power and dependence power, the factors have been classified into four categories [5].

- **(1) Autonomous risk:** This type of risk has weak driving power as well as weak dependence.
- **(2) Linkage risk:** This type of risk has strong driving power as well as strong dependence. Linkage risks are unbalanced.
- **(3) Dependent risk:** This type of risk has strong dependence power but weak driving power.
- **(4) Independent risk:** This type of risk has strong driving power but weak dependence power [10].

Figure 4: indicates the MICMAC analysis.
5. Analysis
In this research 8 risks are identified. Among these risks political risk and disruption risk is the main or driver risk which increase the capacity of other risk also. In political risk there are many factors which are responsible for risk in production system like risk of internal conflict and violence, stability of local currency, disruption through local strikes, change in government policies, regional instability, cost in securing staff security, corruption level at host location etc. Due to these factors overall, political environment may be disturbed on multiple disciplines related to Production system. Disruption risk arise from two factors i.e. equipment malfunction or system failure and natural hazards (Earthquakes, Hurricanes, and Storms). Any disruption can have a dramatic impact on the entire production system. From time-to time production system become vulnerable to various kinds of disruptions which cause huge loss of production system.

6. Conclusion
In this research authors identified 8 risks i.e. Production risk, Organisational risk, Schedule risk, Quality risk, Political risk, Operational risk, Coordination risk, Disruption risk that may affect the performance of production system. An ISM model and MICMAC approach is used to determine the relationship between them. They classify the risks under four types namely independent, linkage, dependent and autonomous. The final results attained with the help of ISM. In future we can use structural equation modelling (SEM) to find how much percentage drivers affect the production system.

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