# MULTI-SOURCE DISTURBANCE MODELING AND ANALYSIS FOR INTELLIGENT MANUFACTURING

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*In view of the low productivity caused by multi-source disturbances in the actual production environment of the intelligent manufacturing, three basic criteria (service, quality, and cost) and four sources (personnel, equipment, scheduling, and material) are proposed to divide the disturbance. Based on the Failure Mode and Effect Analysis (FMEA), a new disturbance order index, disturbance-universal gravity, is proposed to combine the universal gravity to redefine the evaluation method of disturbance risk value. Finally, among these risk values, the differentiation index is used to obtain the critical disturbances, which provides the manager with a way to find the disturbance source that has the greatest impact on the workshop.*

**Keywords**: intelligent manufacturing; FMEA; disturbance; management

## 1. Introduction

Smart Manufacturing is very critical for the modern industry [1]. In the circumstances of market competition, the managers would pay more attention to get more benefits from the workshop intelligent reform. It was crucial that higher throughput can reduce cycle time while increasing the number of wip (work in process) [2]. Disturbance in the workshop has tended to be associated with the adjustment of the production capacity and production to meet the different needs of each period so that it will affect service, product quality, and cost for suitable production capacity and production. If the company master three indicators better, the company's brand value would be better [3]. It can improve the throughput to enhance the competitiveness of an enterprise in the market through the disturbance of alleviation [4].

The workshop is the integration of a series of equipment to complete the order of the batch or batches production of a basic production unit. When the disturbance occurred in the production cycle, there would be consequences, including the production output, production capacity, customer service quality, product cost, and enterprise competitiveness [5]. It considers that the disturbance is

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an unusual event that leads to the production stoppage. There are numerous root causes for production stoppage, but industry norm is to explicitly consider only a fraction of the root causes. The current mainstream disturbance reason is related to equipment production, such as equipment maintenance and initialization. However, others, such as materials, personnel, or information related disturbance to workshop production capacity, have different degrees of influence [6]. Ahmad et al. proposed [7] four principles for stability of the production system (people, materials, equipment, and scheduling). Similarly, Smalley [8] adapted these and considered as manpower, machines, materials, and methods as basic modules of manufacturing.

Zhang et al. [9] had analyzed the interference factors of the impact of scheduling in order to generate a scheduling scheme which was not sensitive to disturbance. But it is difficult to predict and evaluate in the complicated workshop associated with kinds of disturbances. Liu et al. [10]presented how to carry on the fast response to all kinds of disturbances. It is lack of reasonable evaluation of the correlation of the disturbances. Chen et al. [11]designed the workshop production scheduling model and put forward three kinds of typical disturbances: equipment failures, emergency mechanisms of single well as the new orders. And more disturbance factors will be discussed furthermore. In trial-manufacture mould production, Yang et al. [12] had proposed that high frequency interference accidents such as reworking and repairing had an impact on the production progress together and put forward a method using the load balancing production control to evaluate the disturbance. The combination of disturbance in the workshop and control algorithm will be improved.

So far, the studies were mostly on dynamic scheduling and the disturbance of the quantitative analysis of factors that influenced production [13]. Zhang [14] had surveyed to highlight the disturbance on the performance of products while in the specified workshop production (throughput) under the standard of performance and quantify the influence of the factors of disturbance degree. It provided a specific reference for the future perfect digital twin workshop. Therefore, a comprehensive analysis of the disturbance is how to design and operate a workshop. The understanding of the disruption mostly stayed in the macro sense perception.

This paper presents a new disturbance analysis modeling method for the actual production workshop. In this paper, we study how the workshop run efficiently to provide implement workshop managements scientific methods, and the four disturbance source and combining with three evaluation criteria (service, quality, and cost). The production managers could extract more quickly and efficiently from various disturbances associated with this main shop disturbance, according to the specific realization of disturbance prevention, stable and efficient operation management work well for the workshop.

## 2. Problem Statement

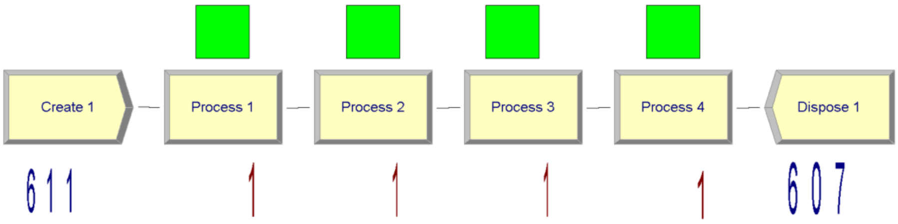


Fig 1. Arena workshop production modeling

We have got instances to survey of 111 companies and organizations in the United States form Sawhney [15] team's research. Then we got the disturbance of a traditional FMEA risk value of RP. In this paper, a simple simulation had made through Arena software, which leads to the disturbance problem. New disturbance gravitation was built compared with those of the traditional method. We sort these values and analysis the relatively high risk of disturbance from the resulting disturbance to serve the factory, including the occurrence of the disturbance, the position of the disturbances, the disturbance frequency disturbance degree, the number of disturbance, and the impact of production performance.

Through the Arena software, as shown in figure 1, the production processes were made respectively to simulate the parts of the production around the workstation S1, S2, S3, S4 after the four workstations. The green boxes represent that the state of each process is normal. The simulation had run over 610 minutes, while every workstation processing parts took 1 min. In the case of no disturbance, 611 parts are input and 607 parts are acquired as throughput, among which 4 parts are in process. Fault information is shown in table 1, including failure according to the counting model, which obeys the standard normal distribution $N(\mu, \sigma^2)$ and is the ideal environment (no disturbance) under the production results of the comparison. When adding fault F3, the F3 standard is ideal models - trouble-free to provide a more standard for other cases in which downtime was 0 min.

*Table 1*

**Fault information**

| Fault | Failure distribution | Downtime/min |
|---|---|---|
| F 1 | N (80,0.2) | 10 |
| F 2 | N (50,0.2) | 10 |
| F3 | 10 | 0 |
| F 4 | N (80,0.2) | 20 |
| F5 | N (80,0.2) | 25 |
| F 6 | N (60,0.2) | 10 |
| F 7 | N (70,0.2) | 10 |

After 610 minutes, the results were shown in Table 2, including the output (Output), parts of processing Time (Cycle Time), work in process (WIP).

*Table 2*

*The simulation result of Arena*

| Case | Fault combination | Output/pc | CT/min | WIP/pc |
|---|---|---|---|---|
| 1 | Ideal | 607 | 4 | 4 |
| 2 | S1-F1 | 547 | 33.67 | 34 |
| 3 | S2-F1 | 547 | 33.67 | 34 |
| 4 | S3-F1 | 547 | 33.67 | 34 |
| 5 | S4-F1 | 547 | 33.67 | 34 |
| 6 | S1, S2-F1 | 537 | 34.13 | 35 |
| 7 | S1, S2, S3-F1 | 537 | 37.07 | 38 |
| 8 | S1, S2, S3, S4-F1 | 527 | 44.72 | 45 |
| 9 | S1-F2 | 507 | 50.65 | 51 |
| 10 | S1, S2-F2 | 497 | 53.38 | 55 |
| 11 | S1, S2, S3-F2 | 497 | 53.38 | 55 |
| 12 | S1, S2, S3, S4-F2 | 497 | 64.06 | 63 |
| 13 | S1-F4 | 487 | 55.87 | 58 |
| 14 | S1-F5 | 474 | 66.5 | 67 |
| 15 | S1-F6 | 527 | 43.64 | 44 |
| 16 | S1-F7 | 537 | 38 | 38 |

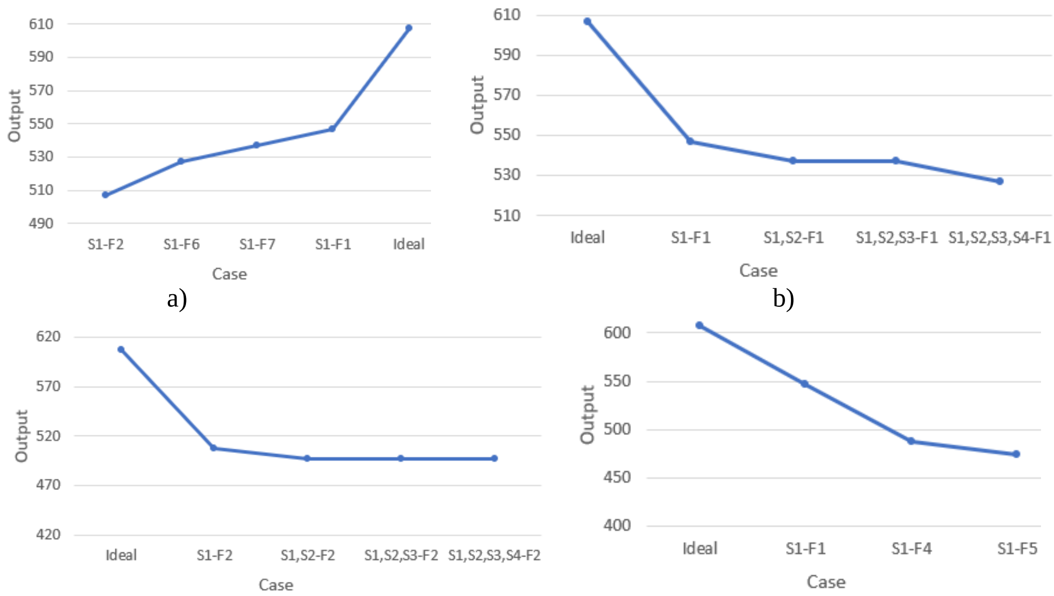


Fig. 2 Failure mode and the output

Conclusion:

(1) Compared the case 1 with the rest of the other cases, the faults have a great influence on the output, cycle time, and wip, as shown in table 2.

(2) According to cases (between case 2 and case 5), it shows that the location of the failure in this experiment under the simulation environment and constraints of the output, cycle time, and wip no effect.

(3) According to case 1, 2, 9, 15, 16, the higher the probability of failure (smaller), the less is output, as shown in figure 2 (a).

(4) Between the case 1, 2, 6, 7, 8 and in case 1, 9, 10, 11, 12, the fault occurs more, the number of output is less, as is shown in figure 2 (b) and (c).

(5) According to case 1, 2, 13, 14, the seriousness of the fault (the longer the downtime), the output is less, as is shown in figure 2 (d).

It revealed that the frequency of the machine failures and the seriousness of the fault of the workshop lead to production capacity's difference.

## 3. The classification of the disturbance

Workshop disturbance is a complex problem. There are all kinds of resources related to the disturbance, as it has many stars, planets, and satellites in the galaxy. "Star disturbances," which was treated as workshop disturbance problems, are in the central, and the disturbance framework was inspiring galaxies in the universe. Furthermore, it is a workshop disturbance secondary planets and moons disturbance source around the central star. At the same star level, when the weight is not at the same time, the planets are not in the same level, as the same horizontal planets are in the same realm with equal weight, as shown in figure 3.

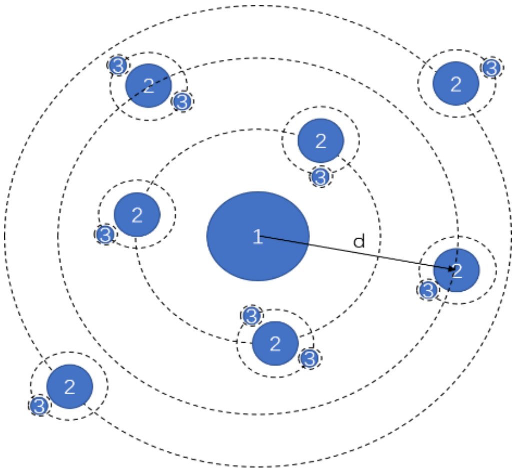

Fig. 3 Disturbance galaxy map

As shown in Fig. 3, 1 represents the workshop disturbance problem. 2 represents primary affiliate disturbance sources around the workshop of the disturbance what refers to the three evaluation standards, including the service-related disturbance, the quality-related disturbance, and the cost related disturbance, respectively. Their different orbit means the different weights, so the closer the distance is, the higher the weight is. Some articles [16] had used AHP or entropy methods to determine each factor's weight. In contrast, some managers or experts had set the specific weight of the company through brainstorming or experts meeting. 3 represents the secondary disturbance sources under the related disturbance source 2, which means four disturbance resources: personnel, equipment, scheduling, and physical disturbance.

## 4. The calculation of value at risk of disturbance

### 4.1 FMEA

FMEA Failure mode and effect analysis had been designed for eliminating dangerous tools in front of the disturbances [17]. The purpose is to find all the possible failure modes of the system, which means solving the disturbance fundamentally to propose solutions rather than later. The method adopts the risk coefficient of RPN to evaluate risk value.

$$RPN = S * D * D \tag{1}$$

In formula 1, S (Severity) is for dangerous fault values, O (Occurrence) is for the failure probability, D (Detective) is for the possibility of a fault. The value defined by the experts and scholars is from 1 to 10. The higher the value is, the higher the risk represents. Either experts or mangers could use FMEA easily what combined with qualitative analysis and quantitative analysis quantitative in the union.

### 4.2 To establish a new method formula

This paper adopts a new risk assessment, which replaces the original RPN value at risk of disturbance to assess the workshop. In galaxies, gravity exists between stars and stars. Gravity formula is for:

$$F = G \frac{m_1 m_2}{R^2} \tag{2}$$

G is constant, and $m_1$ and $m_2$ are astral characteristics inherent in itself. R is the distance between the two stars. Based on FMEA, we study the disturbance factors S (risk), O (value), and D (found). As S and O are their properties, and D is an external factor, we can set up corresponding relationships of the universal gravity. Its formula is:

$$DUG = \omega \frac{SO}{D^2} \tag{3}$$

DUG is a disturbance of gravity, which is the disturbance of risk assessment values, and ω is the weight. DUG expressed a workshop risk prediction ratio between disturbance's attribute factors and external factors, which is different from the traditional method of mixed factors multiply. In the formula, the molecular part represents the value of disturbance of risk value, and it was its inherent attributes indeed. Attribute values depend on the size of the final analysis of the disturbance source to emphasize the disturbance source of hierarchical analysis, in which production operators cannot directly affect these properties. The numerator part represents the possibility of external disturbance, which is directly related to reducing the risk of disturbance. At the same time, production operators can directly affect the size of the attribute values, such as building an online intelligent monitoring system [18], perform regular and active maintenance measures. So the significance is that managers can take many methods to reduce the occurrence of disturbance. The purpose is that we set up DUG is to prevent workshop disturbances from only focusing on fault risks previously. Weight "ω" expresses different disturbance values at the same level in different workshops. S, O, and D values are the same as a traditional FMEA method, an integer value of 1-10. The difference is D value. The bigger the value is, the easier it is detected. The traditional method was just the opposite.

## 5. Case study

### 5.1 Sorting

The framework of disturbance sort is in table 3.

*Table 3*

**Sorting model**

| Workshop | Environment | Para. | | | | Old | New | Sorting | |
|---|---|---|---|---|---|---|---|---|---|
| Standard | Hypothetical | O | S | $D_t$ | $D_n$ | RPN | DUG | Differentiation index | Advice |
| Classification | $C_n$ | | | | | | | | |

- Workshop: This column contains three criteria: service, quality, and cost, four categories: personnel, equipment, scheduling, and material.
- Hypothetical situation: This column shows the managers hope workshop initial operation condition and ideal workshop without disturbances.
- O: When the condition is not satisfied, the probability of disturbances, the value of 1 to 10 integers, as value 1 represents the minimal impact, value 10 represents the most prominent influence.

- S: If the assumptions are not satisfied, the effects were brought by the actual disturbance. Value 1 represents the minimal impact; value 10 represents the biggest influence.
- D: It refers to the possibility, as well as O and S, and the value is 1 to 10. Dt represents the RPN value of D; if the value is higher, it will be more challenging to be detected. $D_n$ represents a new method for calculating DUG; if the value is higher, it will be more easily to be detected.
- RPN: Traditional FMEA evaluation index of value at risk of failure, RPN=S*O*D.
- DUG: Based on an FMEA method of gravity formula, we get a new definition of disturbance gravity disturbance of the workshop. Disturbance value was defined as the different disturbance attractive corresponding to the ones under the ideal standard, and the value is changing. It mainly reflected in three aspects. Firstly, if disturbance parameters S, O, and D are changing with the progress of technology under the same research object workshop, its value is also changing. Second, if disturbances are in the same condition under the same research object workshop, the S value is changing. Then, S, O, and D of the same source are likely different in different workshops. This method divides the disturbance itself attribute and external boundary, established the disturbance, change characteristics of risk, emphasized the importance of disturbance management. DUG is as flowers:

$$Disturbance\_UniGravi = \frac{\omega * Severity * \mathrm{Occurrence}}{Detection^2} \tag{4}$$

Differentiation Index: The higher the value of DUG is, the more the influence of disturbance is affected by the workshop. Some enormous value can extract as an essential disturbance, so the workshop managers need to focus on them more. Here we quote differentiation index (Diff. Index) this concept to find out the influence significant disturbance, and it is listed as one of the critical disturbances if its value is more than 1.

$$Diff.index = \frac{DUG - Avg}{Std} \tag{5}$$

Avg all DUG in for the result data of average; Std DUG for all standard deviation.

Advice: The managers provide suggestions for the disturbance of the workshop.

*Table 4*

**Based on the disturbance DUG results service**

| Workshop Service | Environment Hypothetical | Para. O | S | $D_t$ | $D_n$ | Old RPN | New DUG | Disturbance | Sorting Advice |
|---|---|---|---|---|---|---|---|---|---|
| Personnel | Train staff | 2 | 5 | 5 | 5 | 50 | 0.40 | -0.39 | Training matrix and evaluate training personnel |
| | Personnel available | 3 | 7 | 5 | 5 | 105 | 0.84 | -0.35 | Through plans to ensure that personnel are available |
| | No error | 4 | 7 | 3 | 7 | 84 | 0.57 | -0.37 | Implement the mistake proofing |
| | Effective communication | 5 | 8 | 10 | 1 | 400 | 40.00 | 3.49 | Organizational learning culture communication |
| | Have the ability to staff | 2 | 5 | 4 | 6 | 40 | 0.28 | -0.40 | Strict hiring and training |

*Table 5*

**Equipment disturbance DUG results based on the service**

| Workshop Service | Environment Hypothetical | Para. O | S | $D_t$ | $D_n$ | Old RPN | New DUG | Disturbance | Sorting Advice |
|---|---|---|---|---|---|---|---|---|---|
| Equipment | The required function | 8 | 5 | 6 | 4 | 240 | 2.50 | -0.18 | Improve process capability study and maintenance activities |
| | The required capacity | 1 | 2 | 3 | 7 | 6 | 0.04 | -0.42 | The implementation of active maintenance and SMED |
| | The calibration | 4 | 7 | 8 | 2 | 224 | 7.00 | 0.26 | Measurement system analysis |
| | Communication is normal | 7 | 5 | 2 | 8 | 70 | 0.55 | -0.37 | Establish equipment physical connection |
| | Take the initiative to maintain | 6 | 7 | 6 | 4 | 252 | 2.63 | -0.17 | Implement total preventive maintenance |

*Table 6*

**Based on the service dispatch DUG results**

| Workshop Service | Environment Hypothetical | Para. O | S | $D_t$ | $D_n$ | Old RPN | New DUG | Disturbance | Sorting Advice |
|---|---|---|---|---|---|---|---|---|---|
| scheduling | Predictable scheduling | 4 | 6 | 8 | 2 | 192 | 6.00 | 0.16 | Ensure accurate forecast data report |
| | No special events | 7 | 7 | 10 | 1 | 490 | 49.00 | 4.38 | Scheduling must plan correctly |
| | Correct number of scheduling | 2 | 7 | 6 | 4 | 84 | 0.88 | -0.34 | Use the production report and process table |
| | The right time | 6 | 8 | 5 | 5 | 240 | 1.92 | -0.24 | Use the production report and process table |
| | Normal order order | 2 | 8 | 5 | 5 | 80 | 0.64 | -0.36 | Use the production report and process table |

*Table 7*

**Based on the result of service material DUG**

| Workshop | Environment | Para. | | | | Old | New | Sorting | |
|---|---|---|---|---|---|---|---|---|---|
| Service | Hypothetical | O | S | $D_t$ | $D_n$ | RPN | DUG | Disturbance | Advice |
| Material | Correct number | 6 | 7 | 6 | 4 | 252 | 2.63 | -0.17 | Use production report and process table |
| | Quality qualification | 3 | 4 | 5 | 5 | 60 | 0.48 | -0.38 | Parts design material internal process properly, Use production report and process table |
| | Transfer on time | 5 | 8 | 3 | 7 | 120 | 0.82 | -0.35 | |
| | Implantation of barrier-free | 4 | 7 | 5 | 5 | 140 | 1.12 | -0.32 | Accept standard work; Human resources training |
| | Logistics receiving system | 5 | 8 | 2 | 8 | 80 | 0.63 | -0.37 | Accept standard work; Human resources training |
| | But local transfer | 6 | 2 | 6 | 4 | 72 | 0.75 | -0.35 | Visual monitoring; Follow the SOP for material |

## 5.2 Result

According to Professor Sawhney's team [15] research, some disturbance sort results had listed in table 4, table 7. As these values were hard to choose, this paper presents a new concept at risk of disturbance and established the mathematical model that we can refer to linguistics [19] and the fuzzy sets [20] to quantify the expert evaluation language or intricate process.

According to their workshop, the corresponding DUG parameter model can get critical sources of disturbance and prevent the corresponding measures to prevent abnormal disturbances. We can find that the new method has many differences from the traditional method. As shown in Table 5, the traditional method of sorting the highest disturbance parameter sequence is [6 7 4] from group five, while disturbance parameter in the DUG, the highest sequence is [4 7 2] from group three. As listing second in Table 6, it is [6 8 5] from group four, while the other one is [4 6 2] from group one using the DUG method. In other data sets, we can find when the parameter D is small; the disturbance sorting corresponding may change, because its mathematical model determines it, it is more difficult to find out the disturbance, as value is small. Combined with many detection techniques (such as data mining and visualization technology), it can significantly reduce the influence of disturbance to the workshop, and be more realistic compared with the traditional RPN.

## 6. Conclusion

This paper presents a new method for assessment of disturbance DUG, compared with the traditional method, which can be found from several disturbances as the critical disturbance to provide a solution for managers. It is more important such as staff effective communication and scheduling of special events because the above index values are higher than the other ones. From the enterprise feedback, the disturbance source that we had done is listed as one of the critical reasons, while the rest of the disturbance source is also the common reasons [21]. Based on the three parameters of FMEA, a new method of evaluating the risk of disturbance DUG was made, which distinguishes the disturbance of the external and internal factors, and the researchers will focus on preventing disturbances. After getting the DUG value and differentiation index, "Diff.index", managers can find the critical influence from many ordinary disturbances. The following studies will be on disturbance classification and evaluation of the proposed model to the intelligent manufacturing shop. Besides, deep learning and fuzzy decision methods to improve the veracity and reliability are also the following research directions.

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