AN ANALYSIS OF CORRELATIONS BETWEEN DISRUPTION CATEGORIES IN A HIGHLY CUSTOMIZED MANUFACTURING SYSTEM

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Abstract
The article presents an analysis of correlations among the various categories of disruptions reported in a selected enterprise whose manufacturing system is considered to be highly customized. The authors assumed that in investigation of effects of disruptions may involve a look into the possible links that exit among individual effects. This knowledge should help identify any common root causes of disruptions and, in effect, help manage risks in an organization. To conduct the analysis, was used software that measures correlations between disruptions and the statistical significance of results. Next, they discussed the notions of risk and risk management with a particular focus on companies that produce to the order of individual customers. This point was followed by a presentation of research outcomes, which defined the level of correlation among the identified disruption categories. All this enabled the authors to arrive at conclusions on probable relationships among the reported issues and propose ways to address them.

Keywords:
risk, risk management, highly-customized manufacturing system (production to order of individual customer), correlations.

1 INTRODUCTION
Risk management is central to informed organizational management. In seeking to stay in business and continue to operate manufacturing enterprises, companies face pressures to cater to the demands of individual customers. By responding to such demands, they create highly changeable manufacturing systems riddled with threats that may potentially disrupt operations. The resulting impacts on delivery time and costs translate into specific risks, which enterprises assume. In an effort to help mitigate and proactively manage such risks, the authors embarked on identifying correlations between the effects of adverse events (falling behind schedule), as recorded by the organization they investigated. Historical data was employed for analysis with a view not only to helping identify disruption patterns but also shortening the organization’s learning curve.

2 RISK AND RISK MANAGEMENT IN THE OPERATION OF CUSTOMIZED PROCESSES
Risk entails the absence of certainty. One may consider it “an impact of uncertainty on goal attainment” [2;3]. An alternative approach to distinguishing risks from uncertainties was proposed by Douglas W. Hubbard. He associated uncertainty with the lack of absolute certainty – the existence of more than one option, in which the results/states and effects/values are unknown. Risks too may be described in terms of uncertainty. However, “certain scenarios lead to certain losses, disasters or other untoward outcomes”. Therefore, uncertainty can be defined as a “set of probabilities ascribed to a set of scenarios” while the measurement of risk defines the set of scenarios, each associated with a specific probability and possible losses [1].

The differentiation of potential threats and disruptions depends on a number of factors such as enterprise size, the adopted mode of operating the manufacturing system, product complexity, employee and owner experience, etc. All this affects the level of risk existing in an organization.

To compete in their industry, today’s enterprises must not only deliver their goods on schedule while providing good value for money but also maintain a product offering that satisfies the individualized needs of every customer. Therefore, production managers choose to customize their production, i.e. modify their outputs (products) to customer needs. A closer look at this process shows that mass customization revolutionizes markets based on consumer preferences. In highly customized manufacturing, products are made “in response to the needs of a relatively large market with due account taken of individual customer needs while keeping unit production costs at a level close to that achieved in mass manufacturing” [4].

In an effort to manage risks proactively, one may rely on various information sources. These include:
- Consultations,
- Observations,
- Measurements,
- Document analyses (reviews),
- Historical data analyses,
- Statistical and other reports as well as other secondary knowledge sources,
- Expert surveys,
- Delphi method,
- SWOT analysis.

A valuable source of information may also be the analysis of the correlation between the determinants of a company’s production-logistics system, which allows creating a “picture” of them interdependencies, what is important in the design process of system’s transformation or improvement [5]. By investigating the causes of disruptions, one learns more about their origins. The challenge lies in the fact that specific issues tend to be caused by multiple contributing factors which converge to create a disruption. The data analysis concept is presented in Figure 1. The authors assumed that in investigation of effects of disruptions may involve a look into the possible links that exit among individual effects. This knowledge should help identify any common root causes of disruptions and, in effect, help manage risks in an organization.

1 Defined by the distribution of probabilities.
3 CORRELATION ANALYSIS – CASE STUDY

For a given effect, various methods are applied to identify the causes of an adverse event defined as a disruption in a manufacturing system. However, links between the underlying causes that produce different effects are often ignored. The authors sought to remedy that by using the data of a company whose manufacturing system is highly customized. Such customization not only requires that the company properly organize all spheres associated with standard activities but also adequately plan and operate process design. Changeability in a manufacturing system results not only from the diversity of the goods made but also from differences in order size. In a production system that is tailor-made to meet the needs of individual customers, it is difficult to adopt process standards. As a consequence, disruption prevention also poses a greater challenge.

For the purposes of risk management, the authors assumed that solutions should be found in the correlation between any disruptions identified in a manufacturing system. They looked at disruptions in 258 orders, measured in the man-hours needed to repair their effects, and found that such disruptions have resulted from the reported irregularities. They identified 10 categories which could be linked to over 2000 disruption reports, as submitted between January and October 2015 in the manufacturing system in question. The relevant categories are described in Table 1.

Table 1. Analysis of unscheduled time categories.

| No. | Disruption | Description / scope |
|-----|------------|---------------------|
| 1.  | Damage     | Damage arising in production or during internal handling of vehicle. The man-hours cover repairs or replacement of damaged item(s) as well as any additional man-hours resulting from the technological process / production task sequence. The category also includes tasks imposed by quality control to achieve improvement. The damage may result from erroneous assembly (and specifically from missing process instructions or failure to understand existing instructions) or from orders to install previously damaged subassemblies (workers awarded for the volume of work performed rather than for work done to a prescribed quality standard) |
| 2.  | Technical solution not available during production | Missing technical documentation (from Engineering) forcing production to wait for resolution of a production issue |
| 3.  | Missing parts during assembly | Tasks in the production sequence are completed only partially making it necessary to add previously missing items to already produced vehicles (which is commonly done off production line) |
| 4.  | Production process | Activities associated with the production process that were not completed on schedule due e.g. to worker absence, worker inexperience, etc. The category is also associated with difficulties encountered in scheduling that allows for the completion of unique tasks that are needed to fulfill customer orders. An example is painting, whose time window is strictly specified no matter whether a product is single-colored or e.g. striped – only after a product is made (i.e. once all parts and components have been fitted together) can it be painted |
| 5.  | Instructions/ manuals missing at workstation | Certain tasks however not been scheduled and no time has been allowed for new operations; missing assembly instructions (no standards are developed for the fitting of individual subassemblies) |
| 6.  | Other | Other unscheduled times not classified elsewhere, such as special jobs, the dismantling of previously installed parts, fire alarms/drills, procurements of parts for fitting at customer’s works, etc. |
| 7.  | Supplier error | Substandard (e.g. substandard quality) items supplied to workstation |
| 8.  | Customer change orders | Customer requests submitted during production (after production documents have already been approved) – applies to both late customer requests and retailer failures to provide complete specifications |
| 9.  | Vehicle frame flaws | Defective vehicle frames, e.g. errors in the production of engine housings |
| 10. | Item preparation for assembly | Applies mainly to glass pane preparation (cleaning) for fitting |
The authors then set out to determine whether the individual categories of effects are correlated and what is the extent of such correlations, if any. For the purposes of the study, the results obtained for all orders were divided by the number of products in a given order, thus arriving at figures per production unit. On top of the 10 distinguished categories, another factor was added that defines the number of products per order, the aim being to verify its links with the reported issues.

### Table 2. Correlations among disruptions in the investigated manufacturing system (per unit produced).

| Variable | Correlations (Summary of correlation showing correlation level per unit produced) | Other |
|----------|---------------------------------------------------------------------------------|-------|
| Technical solution not available during production | | Defective vehicle frame |
| Damage | | Supplier error |
| Parts missing during assembly | | Customer change orders |
| Instructions / manuals missing at workstation | | Supplier error |
| Other | | Supplier error |
| Supplier error | | Supplier error |
| Defective vehicle frame | | Supplier error |
| Other | | Supplier error |
| Production process | | Supplier error |
| Item preparation for assembly | | Supplier error |
| Number of products per order | | Supplier error |

In the analyses in question, the authors chose to focus on correlations that were high (in the 0.5 to 0.7+ range, very high (0.7-0.9+) and nearly full (0.9-1.0), for which they employed the ranges proposed by J. Guilford [6]. Moreover, they used software to check data for credibility—the results found to be statistically significant were marked in red.

The identified disruptions (their size in hours) were expressed per unit produced and associated with production batch size variability within the <1, 85> range. The unavailability of a technical solution is correlated most strongly with missing instructions/manuals at a workstation (0.637428). This link may apply in the circumstances in which the concerned parties find that a production-related technical solution is missing, leaving them without a reference for the development of workstation manuals.

The unavailability of a technical solution has also shown a strong cross correlation with damage (0.597590). This may be the result of intuitive (rather than standard-based) work on the part of production-floor workers. Finding themselves at a loss as to how to perform their tasks, the workers take improvised actions which eventually result in damage. Another reason may be a flawed technical solution, which causes damage during assembly tests. Other causes include a defective vehicle frame (0.526669). At times, due to the unavailability of a technical solution, items already fitted need to be dismantled and modified, potentially resulting in damage.

A high correlation, (according to Guilford scale), was also identified between the unavailability of a technical solution and missing parts during assembly (0.558256). Faced with the unavailability of a technical solution, managers are uncertain as to what parts to order and are unable to complete their job within the time required by the supplier.
A study of correlations between missing instructions/ manuals at workstations and errors in frame workmanship found high correlations between the two (0.568542). This may be attributed to links with a third factor – the unavailability of technical solutions during production, which is closely related to both of these kinds of disruptions. Furthermore, missing workstation manuals may result in errors in the performance of internal orders and specifically defects in the production of vehicle frame.

The authors were surprised by the fact that a customer’s change orders/late requests have an only low correlation with the identified issues. One might think that such requests would not only greatly disrupt customized production but also be a strong contributor to issues in the operation of such a production system.

The analyzes also showed the shortcoming of a database and the need to improve it. The most important issue include the problem of proper identification by an employee the disruption category - this issue effect into difficulty with the unambiguous allocation of the disruptions to the category by the workers. Successful corrective actions require an analysis of existing categories in the context of increasing their numbers (making more precise categories) based on the comments and remarks made by employees in the report process.

4 SUMMARY

The study of correlations among the reported disruptions in the selected highly-customized manufacturing system found a number of correlations with widely varying impacts. Of the total of 55 cross correlations identified among 11 categories, 32 were found to be statistically significant.

Considering the specific nature of customized operations, the key conclusion is that no significant correlations appear to arise between the number of products ordered and other categories. It also seems significant that only low correlations arise between customer change orders and other factors, which in the case of tailoring products to customer needs and even at the stage of production, appears to be an interesting and vital conclusion.

The analyzes have shown that the disruptions that are the most labor-intensive to repair are the unavailability of technical solutions in production and damage –the correlations identified for those disruptions turn out to be the highest. Also notable was the high level of correlation with the less significant issue of missing workstation manuals/instructions – the issue may be considered a sign of a poorly organized manufacturing system. Such disruptions may also result from the lack of production process standards and difficulties associated with production changeability that results from the management model adopted by an enterprise.

In conclusion, many analyzes in enterprise management focus on the typical analyses of causes and effects. The authors, by analyzing the correlation between disruptions category, showed that they provide valuable information to the comprehensive risk management in the organization's activities.

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