American Journal of Operational Research 2016, 6(2): 40-47
DOI: 10.5923/j.ajor.20160602.02

Problem Prevention in Industrial Production Process by Means of Manufacturing: An Empirical Study in an Equipment Industry

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Abstract Organizations are invariably subject to several weather in their production processes, such as machine breakdowns, absenteeism, demand variation, among other types of negative occurrences. As a solution, or at least minimizing unwanted effects of these problems, several authors recommend the adoption of Manufacturing Flexibility. This being so, the Manufacturing Flexibility can exist at different levels of the organization and in different types, and each type may contain different aspects. Given the complexity of the issue and seeking to deepen the knowledge of Manufacturing Flexibility, it was executed an empirical research on an equipment industry, analyzing the main dimensions of the flexibilities required for the studied company, in order to prevent the problems that occur in your industrial production process. As results it is observed various types of flexibility that are not demanded by the undertaking, which allows to conduct efforts and investments to those flexibility dimensions that are really necessary, providing reduction of efforts, costs and time.

Keywords Manufacturing Flexibility, Problem prevention, Equipment Industry

1. Introduction

Some authors [1, 2] state that exposure to risk is one of the greatest challenges to the survival of organizations. Thus, taking preventive measures so that the risks do not become a problem is a factor determinant of business activity continuity [3].

Others [4] cite the existence of several risks, of various types, which seem from the external environment up to the most basic level of operations, which requires preventive measures to avoid these risks to become problems. From this perspective, several authors [5-12] recommend the use of manufacturing flexibility to minimize risks in the operating environment.

According to some other authors [13, 14] since that Hayes & Wheelwright defended in 1984 the idea that manufacturing flexibility was one of the main dimensions of competitive strategy in business, there has been a substantial growth in research amount about this theme. However, despite its relevance and it is one of the five competitive strategies in operations in Brazil, studies about manufacturing flexibility are still scarce and rare [15], and this is the primary motivation for the achievement of such a research.

Some authors [16-19] indicate that different manufacturing situations are subject to different kinds of risks and variations, requiring different types of flexibility. However, the multidimensional characteristic of manufacturing flexibility impedes to fit the flexibility degree to be adopted before the existing variables, and this is the second motivation of this work.

Thus, this article focused the flexibility dimensions influence upon risks and problems occurring in manufacture, based on a perception survey of tactical-level staff and being limited to the productive environment of an equipment industry located in Rio de Janeiro. The study uses a sample of five respondents who work in management positions (supervisor, coordinator and production manager), aiming to research the manufacturing flexibility dimensions required by such an enterprise, in order to be anticipated to the problems occurring in its production process. The approach was intentional non-probabilistic by trial, that is, five people were selected intentionally by the researcher because he judged that they had adjectives (knowledge, experience and maturity) that qualify them as ideal respondents.

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Published online at http://journal.sapub.org/ajor
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Thus, it was adopted a questionnaire as a data collection instrument, consisting of open, closed, quantitative and qualitative questions, with attitudinal scales, with priority classification, among other aspects, in order to collect information that answer the research goal with the least time, lowest cost, offering fill facilities for respondents, among other relevant aspects.

In relation to the interface with respondents, it was decided to use an auto filled questionnaire, which can be read and filled directly by respondents in internet website. As for its specific objectives, this work aims to know the main problems occurring in manufacturing, their occurrence frequency and what kinds of flexibilities are indicated to compose an ideal group of flexibilities for the analyzed company.

The paper is organized as follows: Section 2 addresses theoretical framework about manufacturing flexibility, which was the research basis; the following section presents results obtained in empirical research carried out with researched equipment industry and a discussion about them; and finalizing the work, it is found the main conclusions, followed by bibliographical references.

2. Theoretical Substantiation about Manufacturing Flexibility

Watts [20] defines manufacturing flexibility as an ability to implement changes in internal operating environment, in adequate time and acceptable cost, in response to changes in market conditions. As for Olhager [21], it is an ability to adapt to conditions changes by using the existing resources (in short-term).

Slack [22] warns that manufacture needs to be flexible because it has to manage an operation under conditions of variety, risks and uncertainties, allowing the productive process to continue its work. According to the author, flexibility contributes to manufacture performance by improving variables such as reliability, costs and speed.

According to Bengtsson [23], in order to react to changes increasing, reducing the products life cycle and global marketing, flexibility is becoming an important source of competitive advantage for manufacturing.

Correa [24] believes that flexibility appears because of the need to deal with inherent uncertainties and process output variability. Uncertainties and variability lead to changes, which are both planned (they happen as a conscious decision of organization, taken to change the organization itself or its relationship with environment) and unplanned (they happen regardless of organization determination but which the organization really needs to adapt). For example, when the time required by the customer is less than the production time, or when the customer changes the applications deadline, flexibility will increase the ability to answer the needs of this client [9].

Correa [24] also suggested that environmental uncertainty and variability in results are two main reasons (or stimulus) to manufacturing flexibility search. This being so, the stimulus sources could be process, suppliers, customers, society, corporation, other functions and competitors. According to him, the unplanned changes have five main dimensions: size, novelty, frequency, certainty and rate. As a consequence, managers seek to maintain control over the situation, being flexibility a way to be sought, as suggested by model of Figure 1.

Continuing this thought line, Kara [9] points out the needs that lead to flexibility, as shown in Figure 2.

According to Upton [25, 26] and Boyle [10], flexibility in manufacturing can exist at different organization levels - strategic, tactical and operational and consists of several types, such as machine flexibility, manpower, routing, volume and product. Each type can have different aspects, known as a potential, real and necessary flexibility, being measured in terms of states number that can be achieved (range), mobility (impacts caused by changes, such as cost and time to setup) and uniformity (as performance measures change with the changes implemented).

Suarez [27, 28] expounded the concept that the several flexibility types express their effects on the so-called basic flexibilities, or first order, that is: mix, volume, new products and delivery, which are realized directly by consumer, directly affecting the strategic positioning in the market.

Sethi [29] organized flexibility types in a hierarchical structure, which reflects the different levels of production systems operations, besides showing their links, as can be seen in Figure 3.

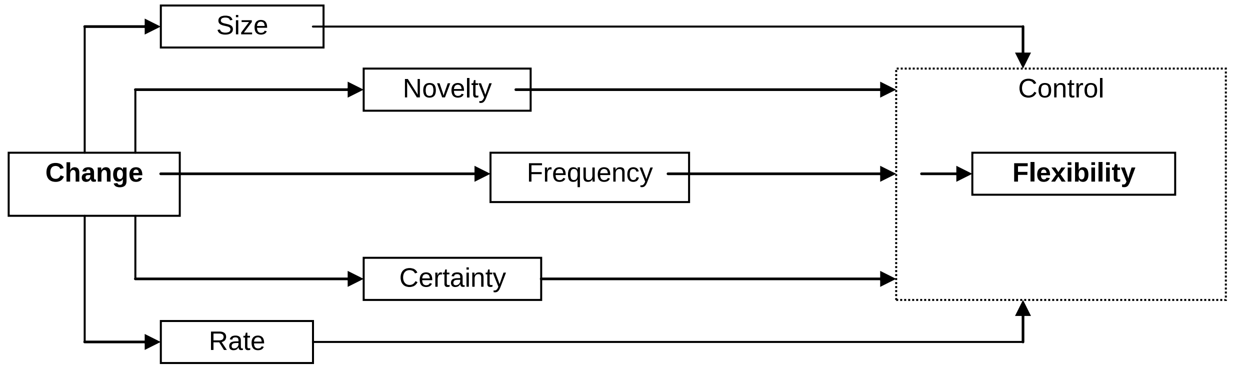

Figure 1. Links between change dimensions and flexibility - **Source**: Correa [24]

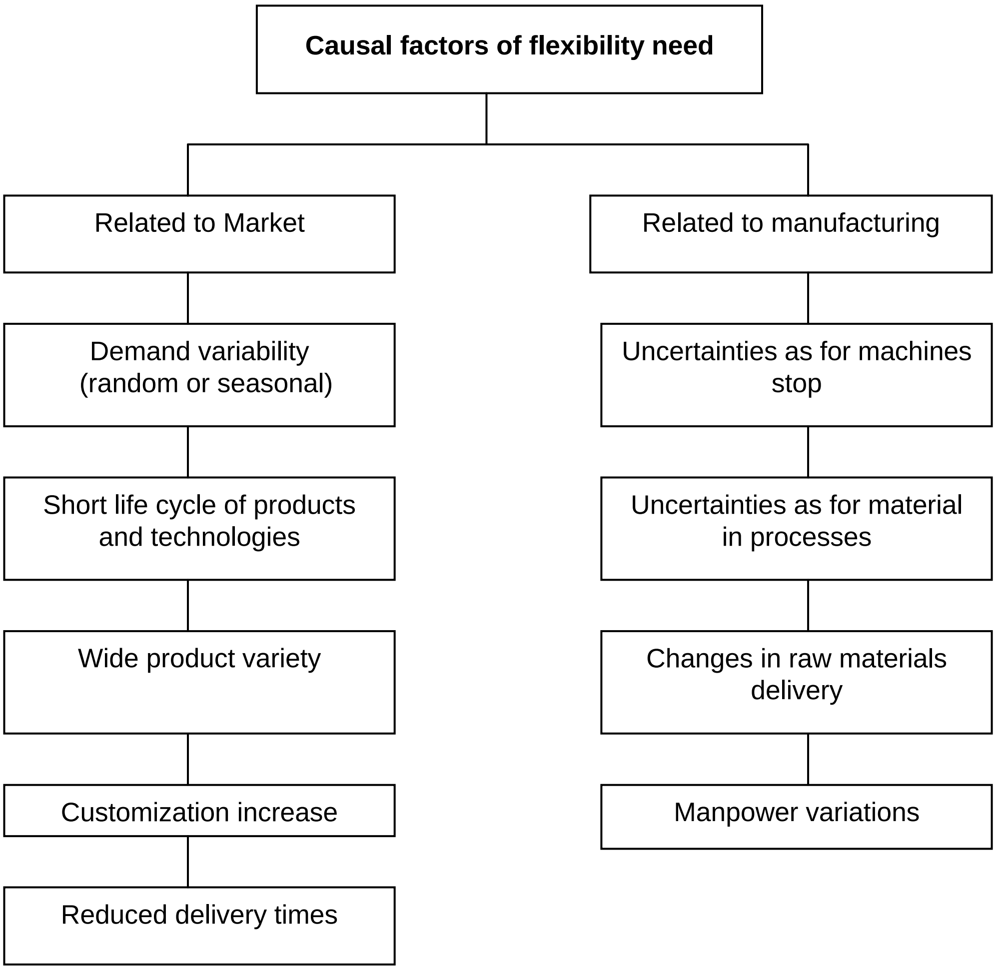

Figure 2. Causal factors of flexibility need - **Source:** Kara [9]

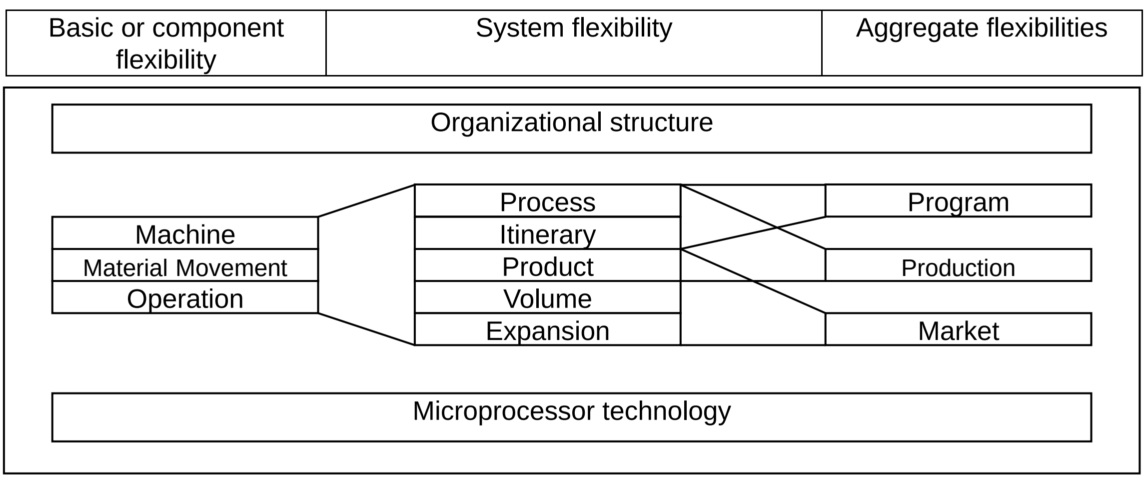

Figure 3. Links among the several flexibility types - Source: Sethi [29]

Regarding the different flexibility types, it is observed the existence of several taxonomies, many times overlapping and conflicting [30-32]; reason why it was selected twelve different types to carry out the empirical research, namely: Delivery flexibility; Expansion flexibility; Machine flexibility; Manpower flexibility; Mix flexibility; Modification flexibility; Material movement flexibility; Operation flexibility; ix) Production flexibility; Product flexibility; Routing flexibility and volume flexibility. These twelve types were chosen because they are the most used by several theme authors [6, 8, 22]. Table 1, below, sets each kind of flexibility.

Table 1. Definition about flexibility types used in empirical research

Dimension	Definition
Machine	Number and variety of operations that a machine can execute without incurring high transition penalties or large changes in performance results.
Manpower	Number and variety of tasks/operations that a worker can perform without incurring high transition penalties or large changes in performance results.
Material moving	Number of existing paths among processing centers and heterogeneity (variety) of material that can be carried along these paths without incurring high transition penalties or large changes in performance results.
Routing	Number of products which have substitute routes and variations extent among the used routes without incurring transition penalties or large changes in performance results.
Operation	Number of products that have substitute sequencing plans and used plans variety without penalties or large changes in performance results.
Expansion	Number and variety of expansions that can be accommodated without high transition penalties or great changes in performance results.
Volume	Changes extent and fluctuation degree in output aggregated level that a system can accommodate without incurring transition penalties or great changes in performance.
Mix	Number and variety (heterogeneity) of products that can be manufactured without incurring high transition penalties or great changes in performance results.
New products	Number and new products variety that are introduced into production without incurring high penalties of transition or great changes in performance results.
Modification	Number and variety of product modifications are carried out without incurring high transition penalties or great changes in performance results.
Delivery	Ability to change planned delivery dates.
Product	Ability to change production for a new product, within a range of defined parts, economically and rapidly.

Source: Adapted from Koste [8]

3. Empirical Research in an Equipment Industry

Empirical research has had two phases, the first one focused on problems analysis that occur in manufacturing process of an equipment industry, and the second to identify the dimensions of most required manufacturing flexibility for attenuation/elimination of problems occurring in the same company.

3.1. Problems Analysis Occurring in an Equipment Industry Manufacture

Analyzing the interviewed respondents responses, it has been observed that the most critical problems in equipment industry are related, in this order, with: i) suppliers; ii) communication problems; iii) manpower, and; iv) demand variation. Other information about problems occurring in the searched company manufacturing with a better detail level, can be seen in Table 2, which has been developed to condense and facilitate data interpretation. Before exploring it, however, it is necessary to clarify its components, as follows:

- The 'problem type' column informs problems types occurring in the studied company, according to respondents perception, agglutinating them by similarity; numbers in brackets represent how many respondents have cited the same problem;
- The column 'times cited' reports the times amount that problems of the same family (similar problems) have been cited by a respondent;
- The 'classification' column orders problems by means of negative impact degree to the researched organization, in an ordinal form; the lower the number, the worse the problem;
- The 'p average' column indicates the ordinal classificassions average of previous column;
- The 'frequency' column informs how often problems mentioned in the first column (problem type) occur in the researched organization; numbers in brackets represent the frequencies cardinal value: never (5), seldom (4), sometimes (3), often (2) and always (1);
- Finally, the last column called 'flexibility chosen to solve a problem' may contain an amount of flexibility higher than the amount of mentioned problems.

As to the question Frequency, it appears that problems related to equipment unavailability, communication failures and human errors occur more consistently, compared to other problem types, in the searched company.

Table 2. Analysis of uncertainties, risks and problems for equipment industry

EQUIPMENT INDUSTRY - ANALYSIS OF UNCERTAINTY, RISK AND PROBLEMS							
Problem Type	**Times cited**	**Classification**	**P average**	**Frequency**	**F average**	**PF/V factor**	Flexibility chosen to solve a problem
Parts availability lack because of problems with supplier (3); Weak supply chain (1).	4	1st;2nd;1th;3rd	1.75	Always (1); Sometimes (3) often (2); often (2);	2.00	0.88	Mix flexibility (2); Product flexibility (2); Operation flexibility (1); No application flexibility (1).
Lack of communication throughout the chain (1); communication problems (3); poor communication (1).	5	1st; 5th; 2nd; 2nd; 2nd	2.40	Often (2); Sometimes (3); Alwasy (1); often (2); often (2)	2.00	0.96	No application flexibility (5).
Errors due to process knowledge lack (1); training lack (2); knowledge Loss by firing employees (1).	4	4th; 2nd; 3rd; 1st	2.50	Sometimes (3); often(2); always (1); often (2);	2.00	1.25	Manpower flexibility (4).
Market demand variation (1); request divergent production (2); sudden drop in production (1).	4	3rd; 4th; 4th; 1st	3.00	Always (1); sometimes (3); often (2); seldom (4)	2.50	1.88	Mix flexibility (3); volume flexibility (2); product flexibility (2).
Breaking machine (3); Equipment unavailability (1).	4	3rd; 4th; 1st; 3rd	2.75	Sometimes (3); sometimes (3); often (2); sometimes (3)	2.75	1.89	Machine flexibility (3); operation flexibility (1); volume flexibility (1).
Commitment Lack with dates (1).	1	2nd	2.00	Often (2)	2.00	4.00	Delivery flexibility (1).
Work accidents (2).	2	6th; 3rd	4.50	Seldom (4); sometimes (3).	3.50	7.88	Modification flexibility (2);
Operations requiring inadequate postures (1).	1	8th	8.00	Often (2)	2.00	16.00	Modification flexibility (1)
Inadequate process of shipping and receiving material (1).	1	5th	5.00	Seldom (4)	4.00	20.00	Material motion flexibility (1)
Conflict of priorities (1).	1	6th	6.00	Seldom (4)	4.00	24.00	No application flexibility (1).
High setup (1).	1	7th	7.00	Seldom (4)	4.00	28.00	Machine flexibility (1)

Source: Research Data

3.2. Manufacturing Flexibility Analysis Demanded by an Equipment Industry

Analyzing Table 2, specifically the "chosen flexibility to solve the problem" column, it is observed that for the most critical problems solution identified in previous subsection, the most recommended dimensions of flexibility are: mix, product, manpower and volume. Other flexibility types, properly correlated with their problems in an equipment industry, can be viewed in that table.

Continuing the research, empirical study on flexibilities dimensions in equipment industry has been expanded, by means of Questions 5 and 6 of data collection instrument, as excerpt of it in Table 3.

Information obtained by means of these two questions were also organized in Table 4, which was developed to condense and facilitate data interpretation. Before analyzing it, however, it is necessary to clarify its components, as follows:

- The columns '1', '2', '3', '4' and '5' are referred to the evaluation degree that was counted for each flexibility type, where '1' means the assessed flexibility helps nothing to solve problems in manufacturing; '2' means that it little helps; '3' means that helps reasonably; '4' means it helps a lot; and '5' means that the assessed manufacturing flexibility dimension is essential. The marking of each column with a letter "X" indicates the judgment that the responder made for each flexibility type;

- The 'mean' and 'median' column presents the measures of center arising from the statistical measurement of evaluation columns previously described;
- The 'flexibility types composition' column shows the manufacture flexibility types that the respondents, given the shortage of funds for investment in manufacture flexibility, would choose to incorporate into his manufacturing environment, thus forming the 'flexibility portfolio', that is, flexibility much more appropriate for problems solution in the researched enterprise;
- The 'flex factor' column calculates the competence of each flexibility type to the problems treatment occurring in manufacture [15]. It is noted that the higher the flex factor, the more essential is that kind of flexibility for problems solution in manufacturing.

Once explained how the Manufacturing Flexibility Analysis table (Table 4) has been built, we proceed to its analysis and it can be seen that:

- In general, the machine, manpower, mix and product flexibilities are, as perception of respondents, the most required dimensions by the researched company, these being indicated to form a composition (portfolio) of manufacturing flexibility;
- At the other extreme, the operating, production and routing flexibilities in almost anything help in solving problems in the researched company. This means that this industry type (at least in case of the researched company) does not have to invest in these flexibility types, once their problems nature demands other dimensions;
- The delivery, expansion, modification, movement and volume flexibilities generally help timidly in solving problems, which permits to leave for second plane investments in these flexibilities types.

More information, more detailed, can be analyzed in Table 4.

Table 3. Excerpt of data collection instrument applied to equipment industry

Question 5. For each flexibility type, assign a score from 1 to 5, where 1 indicates that flexibility does not help to solve problems or does not apply; 2 indicates that it little helps; 3 indicates that it helps reasonably; 4 indicates that it helps a lot; and 5 indicates that flexibility is essential for troubleshooting. To do so, simply mark an "X" in the corresponding score for each flexibility type.
Question 6. If on the one hand the company needs to invest (spend money) to acquire flexibility, on the other hand the manufacturing flexibility helps minimize and solve certain types of problems in factories. In theory, the more flexible is a company, the fewer problems it will have, however major investments will be needed. The greatest difficulty is in this dose, that is, how much to invest and in what kinds of flexibility to invest. Thus, we would like to know, in your opinion, what types of manufacturing flexibility you deem necessary for your business.

Source: Research Data

Table 4. Manufacturing flexibility analysis in equipment industry

EQUIPMENT INDUSTRY - MANUFACTURING FLEXIBILITY ANALYSIS									
Flexibility types	**CLASSIFICATION: no help (1); Little help (2); Reasonably help (3); It helps a lot (4); It is essential (5)**							**Flexibility types composition**	**Flex Factor**
	1	**2**	**3**	**4**	**5**	**Median**	**Mean**		
Delivery			X	X X	X X	**4.0**	**4.2**	■■	8.4
Expansion			X X X X		X	**3.0**	**3.4**	■	3.4
Machine					X X X X X	**5.0**	**5.0**	■■■■■	25.0
Manpower					X X X X X	**5.0**	**5.0**	■■■■■	25.0
Mix					X X X X X	**5.0**	**5.0**	■■■■■	25.0
Modification				X X	X X X	**5.0**	**4.6**	■■■	13.8
Movement			X X X	X	X	**3.0**	**3.6**	■	3.6
Operation			X X X	X X		**3.0**	**3.4**		0.0
Production			X X X X	X		**3.0**	**3.2**		0.0
Product					X X X X X	**5.0**	**5.0**	■■■■■	25.0
Routing			X X X	XX		**3.0**	**3.4**		0.0
Volume			X	X	X X X	**5.0**	**4.4**	■■■	13.2

Source: Research Data

4. Conclusions

During the theoretical framework development, it was found that there are, in fact, very few studies approaching the operational risks related to manufacturing, which is a gap that is intended to fill with this research. From the several studies reviewed (most of them not referenced here), approximately 50% used to address financial risks, 20% risks arising from work-related injuries, 20% environmental risks, and only 10% addressed other risk types, including operational risks. Thus, it is evident the relevance of some authors findings about the subject [2, 15] stating there are a lot of risks research in financial sector, however little or no attention has been given to risks in manufacturing.

On the other hand, still relating to theoretical frame, it was found that manufacturing flexibility acts as a competitive advantage source to administer operation under conditions of changes, variety, risks and uncertainties, permitting the production process to keeps on its work at a low cost and with faster response.

With regard to the empirical study, it was observed that the worst problems occurring in manufacture of an equipment industry are listed, in priority order, with suppliers, communication failures, manpower and demand variations. This foreknowledge is desired since the understanding of problems that require more management control assists in the process of systematization of risk monitoring activity.

As to manufacturing flexibility to solve problems pointed in researched company, there are the machine, manpower, mix and product flexibilities. Therefore, if some other company in this business segment does not have time, qualified personnel, capital and other factors necessary to develop a research in its own manufacturing environment, the results presented here provide good indications of which flexibilities could be used in its production processes. Nevertheless, it is recommended the deepening for flexible studies in more companies of the same branch (for instance, three other equipment industries) so that the companies in this industrial sector can, with a greater degree of ownership, define which of flexibility types adopt and what kinds of problems.

When analyzing the research goals, it is believed that the study developed for the company has achieved its purpose, since the main problems occurring in its manufacture have been raised as well as the flexibility dimensions required for these problems solution.

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