Optimizing Production Plan Using Balanced-KPI

Kohsuke Katoh
Department of Management Systems, College of Informatics and Human Communication
Kanazawa Institute of Technology, Kanazawa, Japan
Tel: (+81) 76-248-9427, Email: katohk@neptune.kanazawa-it.ac.jp

Abstract. Among the value chained processes of manufacturing companies, production planning is one of the most important but complicated tasks of which the objective is to determine the best combination of products using the manufacturing facilities and various resources under many constraints for fulfilling customer orders. It becomes more difficult when unusual conditions such as natural disasters occur. Usually, the production planner works upon predefined planning procedures and rule manuals primarily to fulfill customer orders and meeting their delivery dates. However, in unusual cases, the planner must make the plan taking into consideration a wider range of management resources, by utilizing deep knowledge about costs, parts stocks, parts delivery times, etc. After elaborating over a period of a few years on the externalizing to document the hidden expertise of the production planners, This study has introduced the balanced score card system that consists of five perspectives, each of which has KPI objective items and values. This "balanced score card" has contributed to all the planners and the company stakeholders in determining the best plan to be shared as their organizational knowledge that can cope with a wider range of unusual conditions.

Keywords: production planning, balanced score card, key performance indicator, knowledge externalization, decision making.

1. OBJECTIVE

This study is based on the study of production planning knowledge extraction at a medium size assembly factory. The organization of this production planning tried to externalize all the information and knowledge used for its planning tasks, since there had not been enough manuals or documents that can be referred to for the new planners. Most knowledge was documented in Business Flowcharts, Data Flowcharts and Entity Relationship Diagrams. However, we found that the deeper we delved into the knowledge of the planners, the more complicated it became.

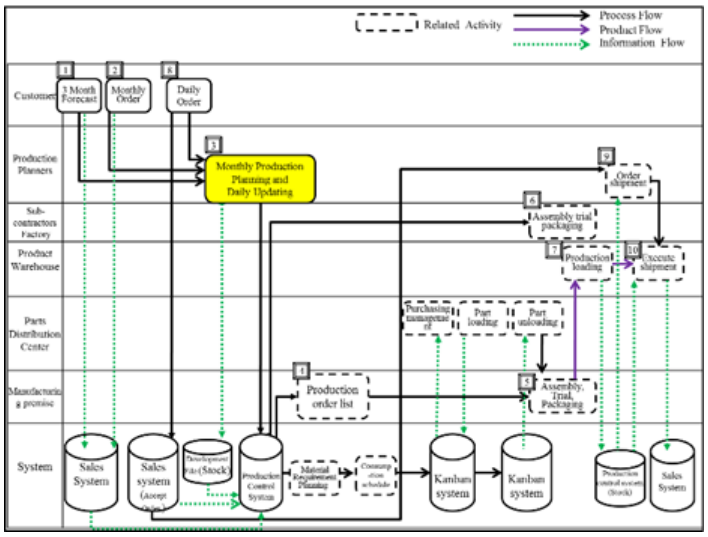
In addition to documenting the procedure manual, it was necessary to clarify how the dynamic decisions for unusual situations should be made. For the purpose of this objective, we introduced a specialized Balanced Scorecard for this production planning processes, with some evaluating methods for any changing decisions to a plan.

2. PRODUCTION PLANNING PROCESS

This study was carried out at a medium sized manufacturing company whose products and production lines had the following profiles.

2.1 Product and production line characteristics

The target products of this production planning are of electronic controllers for gas boilers of 300 different kinds. Among them, 14 kinds were studied for externalizing their production planning process knowledge. Their total delivery



time length is between half a month and three months, while the real production total time length per product is about five hours using 13 production lines.

Figure 1: Total Production Process of the Company

Production plans are created and updated at three different phases: three months in advance, monthly, and daily planning. Figure.1 shows the entire process of the company from order entry to shipment.

The "production control" department is primarily responsible for equalizing the production utilization while the "logistics center" is securely prepared for the necessary parts either from the internal production or by purchasing from other parts manufacturers.

2.2 Knowledge Extraction of the Planning Process

2.2.1 Invisible Planning Knowledge

Three experts were engaged in this production planning. The way they made the production plan was not visible to other people in the company because there were no planning procedure manuals. There was only a fundamental requirement definition document created years before for the production system they use.

The planners have developed their planning knowledge both by their master-apprentice system and their own planning experiences, some of which are classified as "*tacit*" or deep knowledge. On the other hand, documents, procedure manuals or videos are classified as "*explicit*" knowledge.

Sometimes, other department managers inquired about the production plans wondering whether the plans were better than any other alternatives from the company-wide point of view. However the planners were not sufficiently able to explain their complicated and invisible planning process to those external departments. It was too hard for the outsiders to understand without any visible documentation of the production planning process they utilize. Another management problem was that it was also difficult to develop new experts to become a full-fledged professional planners in shorter time than ever.

2.2.2 Quadrants of Planning Knowledge

In order to make sure that the current planning process is good enough to be understood and shared by the management of the company, we worked on a project of extracting planning knowledge.

It was found that knowledge of this production planning extends widely from the fundamental document to deep experienced knowledge. All kinds of information and knowledge related to the process can be referred to Figure. 2.

Figure 2 shows that the whole knowledge can be horizontally divided into two types: "tacit" and explicit knowledge. Additionally, the knowledge structure is layered vertically from the simplest to the most complicated. Tacit knowledge is not written or invisible to persons other than the planners themselves since it is in their heads.

2.2.3 Extracting Planning Knowledge

The difficulty to discover this kind of knowledge could be overcome by carefully observing and imitating how the planner makes a plan in such a way as learning the working steps he does and, video recording his planning behaviors on a terminal screen of the planning system. Every time something to do with the planning knowledge appeared or was suspected in use, it was written onto the data flow diagrams (DFD) of the production process.

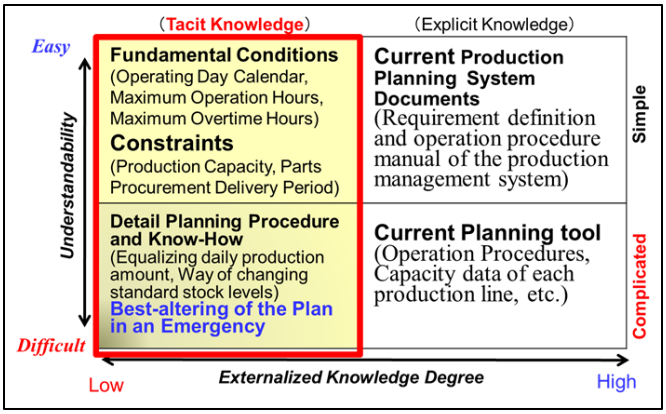


Figure 2: Knowledge Quadrants for the Production Planning

At the same time, all the objects such as production line, part, stock, product, etc., that appear in the process are described by entity relationship diagrams (ERD). These two diagrams significantly contributed not only as a practical and useful documentation tool (writing texts may become too long and complicated), but also made it easier to breakdown each process unit and entity for in-depth knowledge exploring.

2.2.4 Four Layers of Knowledge Depth

Besides the basic information for the production planning process, three levels of knowledge used for the product planning were clarified: "*basic knowledge*" such as fundamental planning processes, "*practical knowledge*" such as utilizing product stocks for shipping and its criteria, and "*deep knowledge*" such as special process for unusual cases. There were four layers of the knowledge (and information) including the basic information.

The basic and the practical knowledge can be extracted and expressed in a job flow diagram or other similar tools, but the deep knowledge is too deeply and widely scattered to be described in a business flow diagrams (BFD).

Ultimately, we decided to use another form of expression or some other way of evaluating the most proper planned outcome.

2.3 Planning Process in "Usual" Situations

In this referencing manufacturing company, there are three levels of production planning. Firstly, in the three month in-advance planning, the following tasks are executed: 1) identifying product type, 2) equalizing daily production amount, 3) summarizing the number of products by each assembly line, and 4) equalizing utilization of all lines. Secondly, in the monthly planning, under the total production capacity, the maximum number of every product amount is fixed. Finally, the daily planning for the following production day is updated enabling manufacture of the required numbers of the company's accepted final product orders.

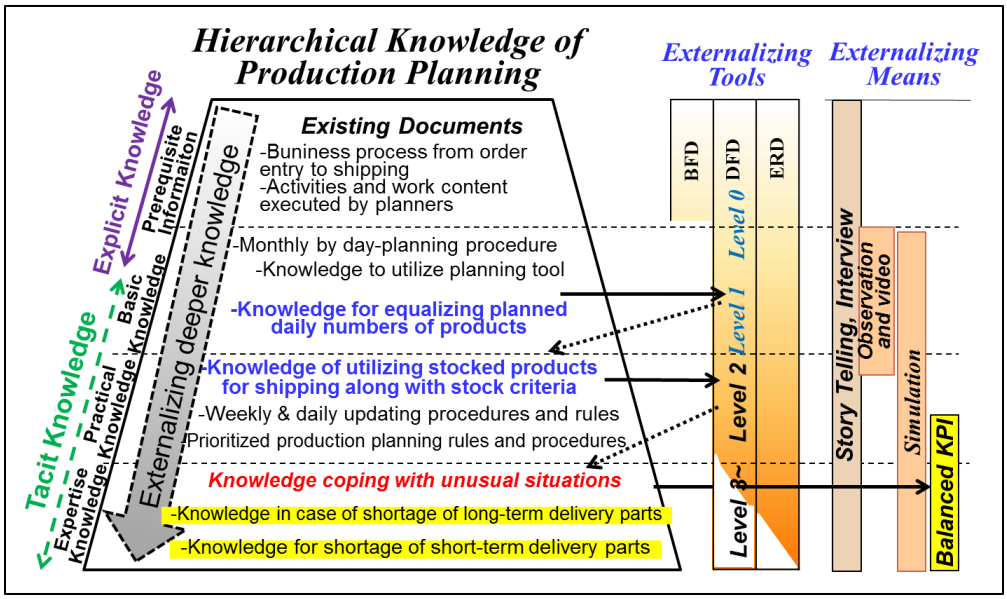


Figure 3: Extracted Knowledge of Production Planning

2.4 Planning Process in "Unusual" Situations

There are several difficult situations that are considered to be unusual and need to be handled properly using exceptional means that are not all described in the procedure manual.

2.4.1 Emergent Change of Component Parts

When a sudden increase of order volume of a product is accepted, supply of some component parts may fall short. A planner has to judge whether an alternative part that is often more expensive than the originally planned one can be used.

2.4.2 Line Failure and Shortage of Product Stock

If any production fails, preserved stocks of the product will be transferred to be shipped causing the product stock level to become lower than the safety one. In order to make up for this shortage, even a single number of the stock shortage may make the alternative production line produce it. In this case, for productivity reason, at least one lot size of the product should be produced that would impact the whole production plan.

2.4.3 Utilizing External Production Lines

When unexpected increased number of product orders has to be accepted, and the company facility's capacity is maximized, the planner has to decide whether to utilize their partner-company's manufacturing line even if it costs more than by the internal production line.

2.4.4 Part Shortage Due to Natural Disasters

In case of natural disasters such as big earthquakes or floods, some component parts bought from the partner companies may not be delivered on time. Production planners must communicate with their purchasing department and the sales department about how to source alternative parts which may cost more than original parts.

2.4.5 Immediate Responsiveness to "Unusual" Situations

To cope with the unusual situations previously described, the standard procedure is roughly described. However, considering any other complicated cases, the planner may not be in a position to decide which changes should be made to alter the plan because there may be many alternative change plans.

Therefore, a comprehensive decision making tool that can both evaluate alternative change plans and be shared among internal stakeholders or different departments is necessary.

3. APPLYING BALANCED KPI

3.1 Decision Criteria of Changing Production planning

Production Planning is usually outlined in the procedure manual and is based on the planners' experienced knowledge. However, each step of the planning procedure does not necessarily explicitly explain the reasoning or rationality of why the procedure step has been developed.

However, in an "unusual" situation, planning will be extremely difficult to determine because whole concerns of internal stakeholders or related organizations need to be taken into consideration. Even the most experienced planners sometimes face moments when they cannot be confident in their changing decisions because they are unsure if they conform to the most proper evaluation criteria. Thus some extra decision tool for the planning in unusual situations is required.

3.2 Necessity of Multiple Views for Decision Making

In the case of an unusual situation, meeting the delivery date is the top priority, production cost and quality issues are also need to be considered.

Sometimes high cost parts need to be used instead of lower cost alternative parts when the latter ones are in short and will not be supplied at that moment. In such a case, if the customer demands the delivery date be met, even under an unusual or difficult situation, the company negotiates a payment agreement with the customer to cover the extra costs.

3.3 Characteristics and Advantages of BSC

We applied the Balanced Scorecard (BSC) system to our production planning operations so that the complicated planning factors can be shown on a single table to be shared with all the internal stakeholders.

BSC originally looked at four (or five) perspectives: Financial, Customer, Internal Process, Learning and Development, later Environment perspective is added as shown in Figure 4. It has been adopted widely as a useful management tool with those four or five perspectives and is used for strategy planning of any size organization from the beginning of the planning to the end of its review for further improvements.

The advantage of this management methodology is that it emphasizes the importance for a company to have multiple perspectives of business objectives that are achieved all together to sustain growth as much as possible or even its existence.

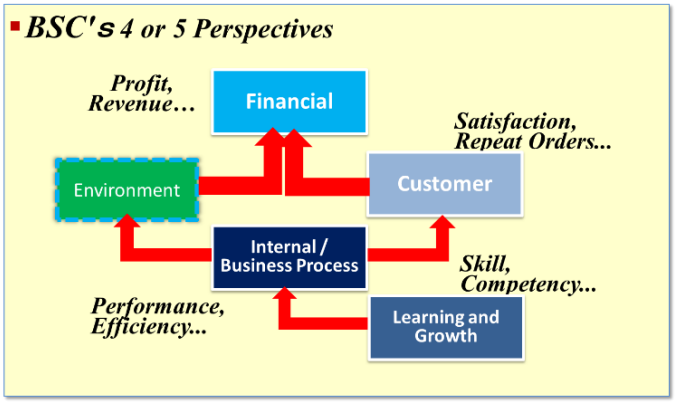


Figure 4: Standard Balanced Score Card (BSC)

3.4 Balanced KPI (Key Performance Indicators)

In this section, the structure of Balanced KPI (Key Performance Indicators) is explained. Balanced KPI, s sort of BSC we developed is capable of dynamically evaluating the changing parameters or values necessary to cope with any unusual situations such as sudden big earthquakes.

3.4.1 KPIs of BSC

Objectives of all five perspectives of the BSC will be set as their critical success factors. Each objective will have a weighted value so that their importance can be compared or judged equally or summarized after each calculation. The objective will also have one or more KPIs of which definition will include both management items and their target values. The values can be either direct numerical absolute figures or relative percentage figures. (Table 1)

The BSC for this production planning is composed of the following perspectives and KPIs.

(1) Delivery Perspective

Meeting the promised delivery date is important for the contracted customer's satisfaction, and the KPIs are defined as: 1) Delayed Shipping Ratio, 2) Annual Average Delayed Days, and 3) The Longest Delayed Days, each of which has its numerical objective figure.

(2) Parts Cost Perspective

The KPIs of this perspective consists of: 1) the ratio of "minimum cost parts" used, and 2) the ratio of "maximum cost parts" used. We aim to maximize KPI #1, while minimizing KPI #2.

(3) Production Line Cost Perspective

There are two assembly facilities for the product. One is the company's facility itself and the other is that of external manufacturing company. Unit costs of production between the two facilities are different; the internal production is less than the external one. So, the KPI is the utilized ratio of external facility which is based on the number of production days of both facilities and the planner tries not to increase this figure.

Table 1: BSC with KPIs as Production Planning Targets

Perspectives	Objectives	Resp. Org.	Measures (KPI)	Targets
Delivery time	・Minimize Delay Time	Sales	Ratio of # Delayed Shipping (# of Delay /Total Shipping × 100)	DD %
			Avg. Days Delayed =(Σ# × Day)/Total #delayed	DD days
			Maximum Days Delayed	MM days
Parts Cost	・Minimize Cost	Sales (negotiation)	Ratio: % Parts of Minimum Cost	PP %
			Ratio: % Parts of Alternatives	AA %
Parts Stock	・On demand	Warehouse, Purchasing	Annual Ratio: % Lack of parts / # used	SS %
			Ratio: Avg. # of Lack of Parts/ # of Required	LL %
Production Line (internal/external)	・Minimize Total Cost other than parts	Production	Annual Ratio #day of external production line used	EE %
Product Stock Level (Safety Stock of Product)	・Avoid Delivery Delay in case of Increased Amount of Production	Warehouse, Prod. Plan	Average # Product stock	# stock
			Σ (# product delayed × days)	Σ# x day
			Σ (# product delayed × days) / # Product shipped annually	ZZ days

(4) Parts Inventory Perspective

The ideal number of product parts for the products is defined so as not to fall short of their stocks. The KPIs are set as 1) the ratio of times of part shortages, and 2) the average number of shortage. Both have maximums that correspond to worst case scenarios.

(5) Product Inventory Perspective

In order to meet the delivery dates despite of the changing amount of daily shipping, some amount of completed products are stocked. The standard stock level is defined from their experiences. The KPIs are: 1) the average number of product inventory, 2) the total number of delay multiplied by delayed days, and 3) the total number of delayed product divided by the total number of products shipped.

Here, 2) and 3) KPIs focus on the failure of the product inventory strategy.

3.4.2 Utilizing Balanced KPI

The objective values should be reviewed annually with the weight values comprehensively although the objective values should always be achieved as much as possible. The daily KPI values are automatically calculated to be compared to the objective values. In addition, a case scenario plan is introduced to record the planned KPI parameters so that any alternative plans can be reserved either to be evaluated, referred, or reused. Such a system enhances the planners' decisions regarding the best alternative plan by changing the KPI values.

As mentioned before, the total value of a plan is calculated as :

$$Vi = \Sigma\,(Wij \times Gij) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

Vi : Total Value of Plan "i",

Wij : weight of objective i,

Gij : "gap" between (target i) & result of (objective a) by Plan "i". Here "gap" could be the difference or the ratio from the objectives.

$i=1,2,\ldots,n;$ n is number of alternatives

$j=1,2,\ldots 5$; number of perspectives

Thus, by comparing the total values of Vi (V_1, V_2, V_3, etc.), the planner chooses the largest valued alternative plan for

changing the original production plan in an emergency situation.

Thus the Balanced KPI system can provide a total value for each alternative change plan created during unusual situations.

Evaluating all KPI values at the same time is necessary to select the best scenario. In order to make the best decision easier, influencing factors for each KPI are introduced to clarify the gaps between the objective values and the setting KPI values. Then, the whole influencing values are calculated from each KPI influencing the value shown as "impact of changing the production plan" in Table 2 (the figures have been replaced with Very High, High, or Medium.) multiplying by each weight value such as w1, w2, w3… also in Table 2. These weight values are previously defined under the agreement among the stakeholder organizations and are reviewed to be updated periodically.

Table 2: BSC with KPIs for Production Planning Evaluation

	Necessary Activities to Achieve the Goal		Indicates the Degree or Gap between the Targets and Current Values	Annual Target Values or Numbers	Values up to Previous Day	Impact of Changing the Production Plan	
Perspectives	**Objectives**	Weight	**KPI (Key Performance Indicators)**	**Target Value**	**Current Value**	**Importance (weight)**	**Responsible Departments**
Delivery Time	Minimize Delivery Delay	W1	Ratio of Delay Shipment	>= xx%	yy%	Very High	Sales, Shipment, Finance
			Average Annual Delayed Days	=< x.x days	y.y Days	High	
			Longest Delayed Days	=< x.x days	y.y Days	High	
Parts Cost	Minimize Parts Cost	W2	Ratio of Low Cost Parts Used	>= XX%	yy%	High	Production, Finance
			Ratio of Alternative Parts Used	=<xx%	yy%	High	
Other Production Cost	Minimize All Other Costs than Parts	W3	Ratio of Running Days at Partner Factories (of all running days at all facilities)	=<xx%	yy%	Medium	Purchasing, Finance
Part Stock	Avoid Parts Deficits or Overstock	W4	Ratio of Parts Deficits	=< x.x days	y.y Days	High	Logistics Center, Production
			Average Annual Deficits	=< xx pieces	yy pieces	High	
Product Stock	Number of Delays of Product Delivery when Order are Increased	W5	Average Annual Product Number of Inventory	XX pieces	yy pieces	Medium	Inventory Control, Shipment
			Σ (#s of Delayed Delivery x Delayed Days)	=< x.x (pieces x days)	yy (pieces x days)	High	
			Σ (#s of Delayed Delivery x Delayed Days)/Total # Shipped	=<xx%	yy%	High	

4. LEVERAGING ORGANIZATION KNOWLEDGE

The Balanced KPI system for changing the production plan explained in the former chapter is utilized from various perspectives and corresponding KPIs.

4.1 Example of a Balanced KPI

Among those KPIs, "keeping delivery date" should always be placed as the top priority in this build-to-order manufacturing company. In unusual situations, other KPI values will be decreased because of lack of parts or a sudden increase of the number of customer orders. However, the total value derived from the Balanced KPI is shared among internal stakeholders guaranteeing an agreement of the change of product plan.

Figure 5: Five View-KPIs spider chart for unusual cases

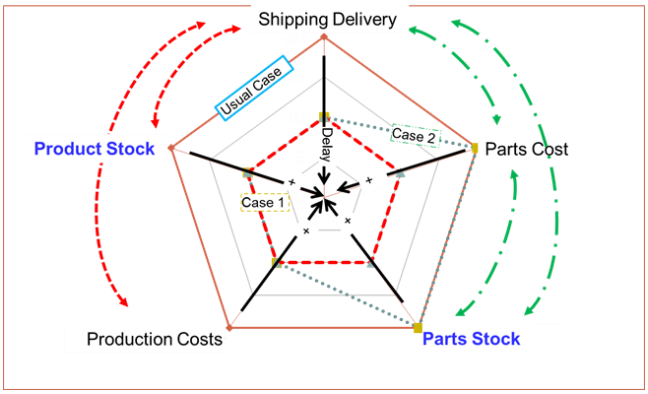


Figure 5 shows a spider chart that consists of five axis of views: order delivery delay, product stock level, production costs, parts costs, and parts stock level. The outermost lines represent the evaluation levels for the usual situation, while Case 1 and Case 2 lines indicate decreased values of all or some integrated KPIs.

4.2 Effectiveness of Balanced KPI

The Balanced KPI system can help any planner of the organization minimize subjective decisions when lacking full confidence to make a decision about changing KPI related parameters for the production plan. In other words, the system makes it possible for any planner to consider all the changing parameters deemed optimum from cross organizational perspectives.

This is because the decided values of each KPI-related parameter can be easily calculated to be evaluated as a whole from the company's managerial point of view. Thus one can select the best changing plan from some alternative plans.

Referring to Figure 5, it is obvious that Case 2 is superior to Case 1.

5. COLLABORATIVE KNOWLEDGE CREATION

We have introduced the Balanced KPI in order to complementarily express the way to make or select the optimum and best decision in an emergency situation. The Balanced KPI would not have been adopted without the process flow description in an easy-to-understand format and structure that expresses all the situations by managements of other departments or the head quarter.

Production planners have the knowledge necessary to cope with unusual situations by themselves, but they often lack confidence needed to make decision for changing the plans. From this point of view, decision making using a balanced KPI has yielded two new knowledge creations. The first is the way to choose the best alternative updating plan, and the second is an improved method of obtaining agreements among managers and staff of all the related departments or stakeholders within the company.

This has been achieved by our continuous study of professional deep knowledge and to describing it in order to enhance the company's performance. This tool was successfully used under an agreement of many departments with their collaborative partners.

6. CONCLUSION

In unusual cases when swift, optimal or satisfactory change to the prepared production plan is required, introducing and utilizing the balanced KPI is effective because it properly enables comprehensive evaluation of the changed plan that can be explained as the result of organizational knowledge. Careful definition of the KPIs and their improvements can leverage the knowledge of response to unusual situations among the organization that leads to increased customer satisfaction as well as their management.

Finally, here are the conclusions.

Balanced KPI for production planning can:

1) Lead the best plan under unusual situations when predefined procedures may not have been covered

2) Externalize/visualize deep expertise knowledge of the production planners

3) Get consensus of the plan among stakeholder departments

4) Be shared and be understood easily

5) Develop planners' capability more quickly

6) Enable planners to feel more confident in their decisions

7) Better sustain the product manufacturing in emergencies

ACKNOWLEDGMENTS

This study is currently in use by the management in the manufacturing company after our study of knowledge extraction of the company's production planning expertise. All the figures except Figure 4 and tables in this paper are our original creation.

We greatly appreciate the cooperation of the personnel who kindly and elaborately explained to us the necessary planning and business processes executed in the company.

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