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EVALUATING USER SATISFACTION WITH NEW FUNCTIONALITIES OF MANUFACTURING EXECUTION SYSTEM BASED ON GENETIC ALGHORITM

Sławomir OLKO[1*] Marek KRANNICH[2]

[1] Silesian University of Technology; slawomir.olko@polsl.pl, ORCID: 0000-0001-5284-6284
[2] Silesian University of Technology; marek.krannich@polsl.pl, ORCID: 0000-0001-6513-5369
* Correspondence author

Purpose: The paper presents the process of evaluation user satisfaction with new functionalities of manufacturing execution system (MES) based on genetic algorithms. New MES system functionalities enabled automatic production scheduling in the event of typical production system disruptions, e.g. failure of a device or production system component. The main outcome of the project was an Integrated Optimisation System (IOS), which was tested in two manufacturing companies in Poland. The article presents an evaluation of the satisfaction of the companies that will be users of the improved system.
Design/methodology/approach: An interview questionnaire was used to assess customer satisfaction, allowing for the evaluation of selected IOS functionalities. The interview was conducted after a system demonstration period in front of two users (companies X1 and X2).
Findings: The overall assessment of satisfaction with IOS is positive in both companies where the demonstration was conducted. The assessments are also positive in the categories examined.
Research limitations/implications: The satisfaction survey results are independent of the main effect of the project, which is to reduce the production cycle time compared to the time resulting from the previous method of scheduling. IOS was implemented by a company offering MES systems. Satisfaction surveys showed that users pay attention to other features of the system, not just minimising production cycle time.
Practical implications: It should be noted that due to the short project implementation time, testing and satisfaction surveys lasted only two months. The surveys were conducted with only two customers. Further implementation work may involve testing the usability of IOS in various production environments.
Originality/value: Many production optimisation systems are described in the literature. Only a small number of these examples of such systems use genetic algorithms. The main value of this article is that it presents an approach to researching customer satisfaction among system users. Institutional customer satisfaction may relate to issues unrelated to the technology used and its effects.
Keywords: production management, Manufacturing Execution System (MES), production optimisation, client satisfaction.
Category of the paper: research paper.

1. Introduction

Nowadays nobody neglects the fact the innovations are the gate towards competitiveness for every kind of enterprises. Innovations not only bring benefits for business but they contribute to social development and improve the situation on the labour market. Governments and regional administration support the innovativeness of enterprises using different measures (financially, fiscally, organizationally or by offering places for developing new ideas). This is in contradiction to so-called Chicago School paradigm for promoting competitiveness and innovation which created a belief in the free market to maximize innovation and productivity (Trott, 2017). Delivering knowledge about innovation management in the form of tailored services is one of the method fostering innovation management used worldwide. Innovation support services or in other words pro-innovative services are designed for enterprises to help them on different stages of innovation process.

From a marketing perspective, according to Philip Kotler, satisfaction can be interpreted as: *the degree to which perceived product characteristics meet the buyer's expectations*. Satisfaction is therefore a feeling that can be measured on a scale (Kotler, 1994).

The assessment of the level of satisfaction is determined by comparing the product attributes that the consumer noticed with their expectations.

Thus, the level of satisfaction is influenced, on the one hand, by the customer's expectations and, on the other, by the overall offer provided by the supplier. Satisfaction is understood as conformity with expectations. A.B. Palacio and G.D. Meneses (2002) highlight three elements:

- a general emotional response of varying intensity,
- focus on the product, purchase, and/or consumption,
- an evaluation that may vary depending on the situation and over time.

The literature presents various models of customer satisfaction (Furtak, 2003). Expectation-disconfirmation model – consistent with the assumptions described above.

1. Equity model – the customer compares the costs incurred and benefits received with the costs and benefits of the seller (satisfaction occurs when the customer's costs and benefits are similar to those of the company).
2. Emotional model – satisfaction is perceived as a state of positive emotional reactions associated with the evaluation of the product.

The most well-known model is the expectation-disconfirmation model, which assumes that the level of satisfaction is a function of the difference between the received and expected product attributes.

As a result of this evaluation, the buyer experiences one of three levels of satisfaction:

- dissatisfaction,
- satisfaction,
- delight.

Research shows that a high level of customer satisfaction stimulates the development of loyal attitudes, which in turn generates long-term relationships with the company (Drapińska, 2011). To have satisfied customers—in accordance with the expectation-disconfirmation model—it is necessary to meet the expectations of the recipient. Consequently, customer expectations are considered "one of the most important variables that an organization should monitor and manage". When considering the issue of customer satisfaction, it is important to remember that "the longer the relationship, the greater the likelihood of a gap between the received offer and expectations". The level of satisfaction with the service provider – over the long term – may therefore be lower than at the beginning of the relationship. However, if the customer remains satisfied, they continue to be committed to the organization (Urban, Siemieniako, 2008). Proper management of customers needs and expectations is therefore one of the most important activities determining a company's success in a turbulent and demanding market (Drapińska, 2005).

The customer satisfaction survey was conducted as part of the project "Research and Development Work on the Development and Application of a Genetic Algorithm for the Optimization of Production Management". The primary goal of the project was to determine the conditions for the application of genetic algorithms in the scheduling of production orders in the Industry 4.0 environment. The practical results, consisting of an actual reduction in the length of production schedules, are presented in an article by Janke et al., 2023. In this article, we present how new system functionalities such as Integrated Optimisation System (IOS), have affected customer satisfaction with the MES.

2. Methods – Assumptions regarding satisfaction research

The study of user satisfaction with the application of the Integrated Optimization System (IOS) was conducted in two stages:

- Stage 1 covered the period before the implementation of the IOS in the cooperating enterprises, summarizing the functioning of the production planning system then in use, as well as the supporting IT tools.
- Stage 2 covered the period after the implementation of the IOS for production planning at the user's site.

The research was carried out in two companies where the IOS was implemented, namely:

1. X1 – engaged in the production of finishing materials for the construction industry.
2. X2– engaged in product packaging for large manufacturers.

In both research stages, the diagnostic survey method was applied, using the technique of a structured interview. The interviews were conducted with employees of the enterprises where the IOS was implemented, specifically those directly involved in the production planning process.

STAGE 1

The interview for Stage 1 was conducted using a questionnaire, the structure of which included the following questions:

Issue 1. Please describe how the currently used production planning system in the enterprise functions. Please provide:

a) What is the production planning period?
b) Who is responsible for handling the production planning process?
c) How does the production planning process proceed?
d) What systems (software applications) are used in the planning process?
e) What types of disruptions to the execution of the production schedule occur most frequently?
f) How often do disruptions in the execution of the production schedule occur, and what impact do they have on the production schedule?

Issue 2. Please describe how disruptions in the execution of the production plan are handled.

a) Disruption: machine breakdown

- How is this type of event taken into account in the plan? What is the frequency of such disruptions?
- What is the duration of disruption handling (from the moment the disruption occurs, through the decision to modify the production plan, until a new production schedule is generated)?
- What are the consequences for order fulfillment (e.g., impact on deadlines, use of production resources, execution of orders planned for the scheduling period)?
- What are the alternative possibilities for transferring tasks to other machines?

b) Disruption: absence of operator(s)

- How is this type of event taken into account in the plan? What is the frequency of such disruptions?
- What is the duration of disruption handling (from the moment the disruption occurs, through the decision to modify the production plan, until a new production schedule is generated)?
- What are the consequences for order fulfillment (e.g., impact on deadlines, use of production resources, execution of orders planned for the scheduling period)?
- What are the alternative possibilities for transferring tasks to other machines?

c) Disruption: introduction of an urgent order into the production plan

- How is this type of event taken into account in the plan? What is the frequency of such disruptions?
- What is the duration of disruption handling (from the moment the disruption occurs, through the decision to modify the production plan, until a new production schedule is generated)?
- What are the consequences for order fulfillment (e.g., impact on deadlines, use of production resources, execution of orders planned for the scheduling period)?
- What are the alternative possibilities for transferring tasks to other machines?

d) Disruption: order cancellation

- How is this type of event taken into account in the plan? What is the frequency of such disruptions?
- What is the duration of disruption handling (from the moment the disruption occurs, through the decision to modify the production plan, until a new production schedule is generated)?
- What are the consequences for order fulfillment (e.g., impact on deadlines, use of production resources, execution of orders planned for the scheduling period)?
- What are the alternative possibilities for transferring tasks to other machines?

Issue 3. How do you evaluate (on a scale of 1 to 5, where 1 means complete dissatisfaction and 5 means complete satisfaction) the currently used production planning system in the enterprise?

Taking into account the earlier partial evaluations, please provide a generalized/overall assessment of the functioning of the system on a scale from 1 to 5 (where: 1 means complete dissatisfaction with the functioning of the system, and 5 means complete satisfaction).

STAGE 2

The interview for Stage 2 was conducted using a questionnaire, the structure of which included the following questions:

Issue 1. Please describe how the implemented IOS (Integrated Optimization System) for production planning functions in the enterprise. Please provide:

a) Does the IOS support the production planning process in accordance with the existing standards?
b) Who is responsible for handling the production planning process using the IOS?
c) What types of disruptions in the execution of the production schedule have you taken into account in calculations using the IOS?

Issue 2. Please describe how disruptions in the execution of the production plan were handled.

a) Disruption: machine breakdown

- What was the frequency of disruptions?

- What was the duration of disruption handling (from the moment the disruption occurred, through the decision to modify the production plan, until a new production schedule was generated)?

b) Disruption: absence of operator(s)

- What was the frequency of disruptions?
- What was the duration of disruption handling (from the moment the disruption occurred, through the decision to modify the production plan, until a new production schedule was generated)?

c) Disruption: introduction of an urgent order into the production plan

- What was the frequency of disruptions?
- What was the duration of disruption handling (from the moment the disruption occurred, through the decision to modify the production plan, until a new production schedule was generated)?

d) Disruption: order cancellation

- What was the frequency of disruptions?
- What was the duration of disruption handling (from the moment the disruption occurred, through the decision to modify the production plan, until a new production schedule was generated)?

Issue 3. How do you evaluate (on a scale from 1 to 5, where 1 means complete dissatisfaction and 5 means complete satisfaction) the IOS used for production planning in the enterprise?

Taking into account the earlier partial evaluations, please provide a generalized/overall assessment of the functioning of the IOS on a scale from 1 to 5 (where: 1 means complete dissatisfaction with the functioning of the system, and 5 means complete satisfaction).

3. Results and discussion

Stage 1 of the conducted interview concerned the currently used production planning system in the enterprise, as well as the supporting IT tools. It was intended for respondents directly involved in the production planning process in the enterprise.

In Issue 1, the respondents reported:

X1

A monthly production planning period is in place, involving planners and foremen, i.e., a combination of the line level responsible for task execution with the higher operational level. The entire process is visualized through a production schedule. Excel and Comarch ERP XL software are used in the planning process. The most frequent disruptions identified were urgent orders and investments. Respondents were unable to specify the frequency of disruptions, as in their opinion it depends on the situation — e.g., the schedule is not fully executed in order to fulfill an urgent order, or an additional shift is added, etc.

X2

The production planning process is weekly, with additional detailed daily plans. It is managed by a planner without the involvement of line employees. The process follows previous arrangements: a customer forecast is received and then the plan is entered into supporting tools as agreed. Excel, Comarch ERP XL, Importer, and Magic are used in the planning process.

The main disruptions include:

- Delayed deliveries.
- Machine breakdowns.
- Quality problems.

The frequency of disruptions during schedule execution is currently being monitored. Their direct effect is longer task completion times, which subsequently disrupt further planning processes.

In Issue 2, the respondents reported:

X1

a) In the case of a machine breakdown, the company is unable to determine repair time, as it depends on the defect. Sometimes it is 5 minutes, other times 3 days. About 70% of products manufactured on the concrete line can be transferred to another line. In extreme cases, manual production is launched, or production is outsourced.
b) A lack of operators is treated as a breakdown, and the production plan is postponed to the next day.
c) In the case of urgent orders, the schedule is marked in color and an additional email notification is sent. Duration: if it is only about schedule changes, it takes about 10 minutes.
d) In the case of order cancellation, the schedule indicates until which day the goods are to be produced. If the order is canceled, it is removed from the schedule and an additional email notification is generated.

X2

a) Machine breakdowns are not included in the weekly plan — repairs are carried out on an ongoing basis. At the beginning of the year, a maintenance schedule is set, and machine downtime is only planned according to this schedule. Average downtime is 6% of total machine availability time across all production shifts.
b) The absence of an operator does not disrupt machine work — processes have been adapted to ensure machine operation and substitution arrangements.
c) In the case of urgent orders, operational adjustments to the plan (so-called "inserts") are made. Their maximum, extreme number is up to 10 per week. If the client requests an additional order, knowing the machine's efficiency (200,000 pcs/week), it is

proposed to move some products already in the plan to the following week. The company's production staff propose specific product codes.

d) Order cancellations occur up to 3 times per month, and only in consultation with the client.

In Issue 3, on a scale from 1 to 5 (where: 1 means complete dissatisfaction, 5 means complete satisfaction), respondents evaluated the currently used production planning system in the enterprise as follows:

a) Reaction time of the system / labor intensity of scheduling: X1 = 3; X2 = 3.
b) Alignment of the plan with actual production (planning effectiveness): X1 = 3; X2 = 4.
c) System response to production process disruptions: X1 = no answer; X2 = no answer (in the case of X2, it was noted that these elements are handled manually).
d) Data and information availability (access time, completeness): X1 = 4; X2 = 4.
e) Integration with other IT systems in the enterprise: X1 = 3; X2 = 3.
f) Coverage of available configuration variables with user needs — possibility of modifying input planning parameters, e.g., calendar: X1 = 3; X2 = 2.
g) Intuitiveness/ergonomics of the scheduling interface: X1 = 4; X2 = 3.
h) Recording of plan history and changes: X1 = 2; X2 = 4.

A comparison of the evaluations of the production planning system used so far is presented in the chart below. The chart shows the assessments of two enterprises – X1 and X2 – in various categories related to the production planning system. From the data, it follows that:

In the category "Reaction time/Labor intensity", both companies rated the system at an average level (3), indicating moderate satisfaction with system speed and scheduling effort.

In "Planning effectiveness", X2 rated the system higher (4) than X1 (3), suggesting that X2 experiences better alignment of plans with production reality.

In "Data availability", both X1 and X2 rated the system at 4, indicating good access to data and information.

In "Integration with other systems", both enterprises gave a score of 3, indicating a need for improved integration with other IT systems.

In "Configuration", X1 rated the system at 3 and X2 at 2, suggesting that X2 experiences greater difficulty in adapting the system to its needs.

In "Intuitiveness/ergonomics of the interface", X1 gave a higher score (4) than X2 (3), suggesting better usability for X1.

In "History recording of changes", X1 rated the system low (2), indicating significant shortcomings in this area, while X2 rated it at 4, suggesting much better functionality.

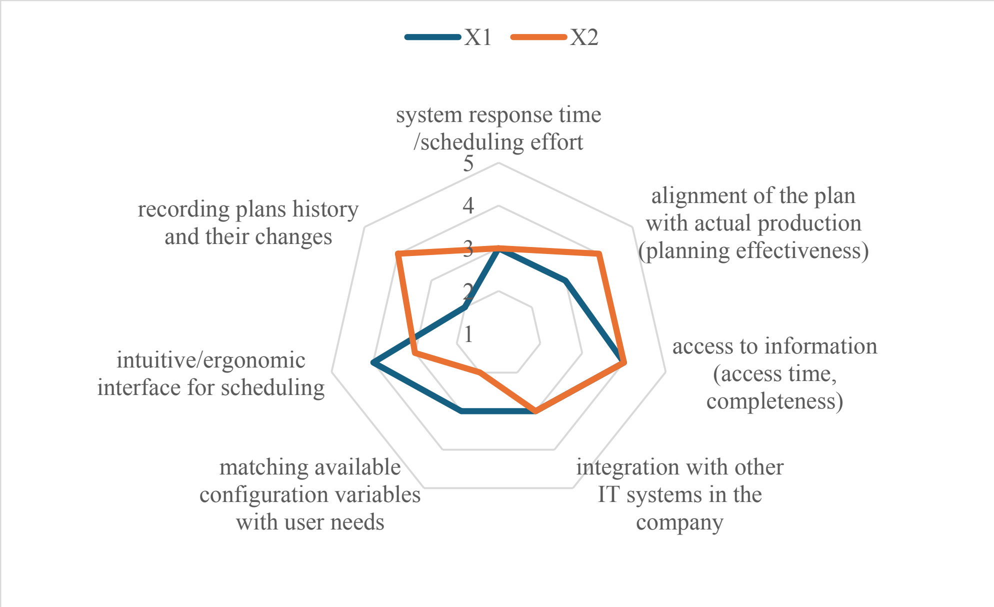

Figure 1. Comparative analysis of production planning systems in companies X1 and X2.

Source: own elaboration.

Stage 2 of the conducted interview concerned the production planning system in the company after the implementation of the Integrated Optimization System (IOS) at the user's site, as well as the supporting IT tools. It was intended for respondents directly involved in the production planning process in the enterprise.

Results of the satisfaction survey in X1 company

In issue 1, the respondent indicated that the IOS supports the production planning process, and in line with previous standards, it is operated by the planner and the production manager. In the execution of the production schedule, when calculations are made using the IOS, the following factors were taken into account: a new ad hoc order and a machine breakdown.

In issue 2, concerning the handling of disruptions in the execution of the production plan, one case of a disruption in the form of a machine breakdown was reported. Regarding the time taken to handle the disruption—from the moment the disruption occurred, through the decision to modify the production plan, to the generation of a new production schedule—the respondent indicated 1 hour. No disruptions in the form of a lack of operator(s) were observed.

For the disruption "introduction of an urgent order into the production plan"—this occurred twice. Regarding the time to handle the disruption—from the moment the disruption occurred, through the decision to modify the production plan, to the generation of a new production schedule—the actual time indicated was 1 hour. The disruption "order cancellation" did not occur.

In issue 3, i.e., the assessment on a scale of 1 to 5 (where 1 means complete lack of satisfaction, and 5 means complete satisfaction) of the IOS used for production planning in the company, the following responses were indicated:

- system response time/workload required to create the schedule – **5**,
- alignment of the plan with production reality (planning effectiveness) – **5**,
- system response to disruptions in the production process – **5**,
- availability of data and information (access time, completeness) – **5**,
- integration with other IT systems in the company – **5**,
- alignment of available configuration variables with user needs – possibility of changing input planning parameters, e.g., calendar – **5**,
- intuitiveness/ergonomics of the scheduling interface – **4**,
- recording the history of introduced plans and their modifications – **3**.

As can be seen from the respondent's indications, the results can be considered very good and positively influencing the functioning of the company. The only exceptions are slightly lower-than-very-good ergonomics and intuitiveness of the interface, and the mid-scale rating for the ability to record introduced plans and their modifications.

The generalized assessment of the IOS (on a scale of 1 to 5, where 1 means complete lack of satisfaction with the system's operation, and 5 means complete satisfaction) was indicated as **5**, which means full user satisfaction with the use of the IOS

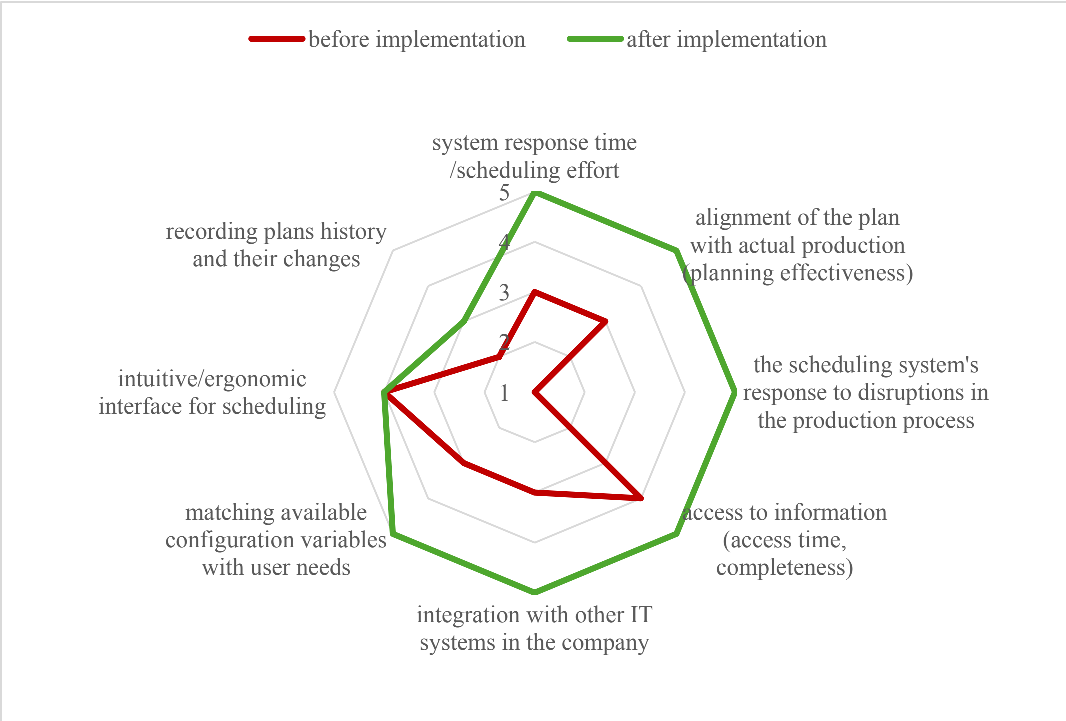

Figure 2. Comparison of X1 customer satisfaction ratings in selected areas before and after IOS implementation.

Source: own elaboration.

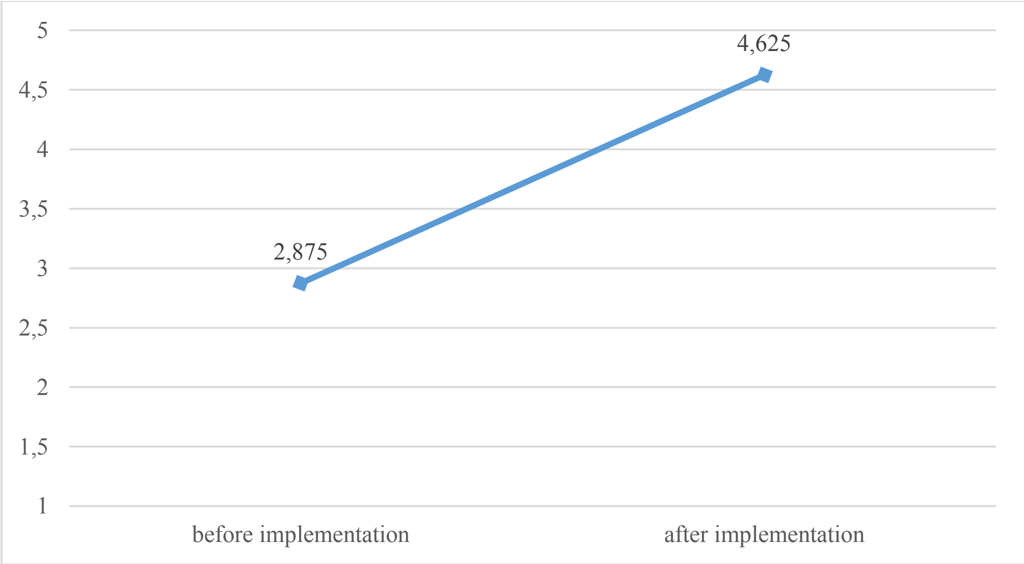

Figure 3. Comprehensive client satisfaction evaluation for X1.

Source: own elaboration.

Satisfaction Survey Results in the X2 Company

In Issue 1, the respondent indicated that the IOS supports the production planning process, which, in line with existing standards, is handled by the planner and the production manager. In carrying out the production schedule, the IOS calculations took into account the following factors: a new ad hoc order and a machine failure.

In Issue 2, concerning the handling of disruptions in the execution of the production plan, for disruptions of the type "machine failure", 5 such cases were reported. Regarding the duration of handling the disruption—from the moment the disruption occurred, through the decision to modify the production plan, to the generation of a new production schedule—the following times were indicated:

- 1h 40m,
- 2h,
- 30m,
- 40m,
- 10m.

No disruptions in the form of a lack of operator(s) were reported.

For the disruption "urgent order insertion into the production plan," it occurred twice. Regarding the duration of handling this disruption—from the moment it appeared, through the decision to modify the production plan, to the generation of a new production schedule—the actual times indicated were 1 hour in the first case and 20 minutes in the second case. The disruption type "order cancellation" did not occur.

In Issue 3, i.e. the evaluation on a scale of 1 to 5 (where: 1 means complete lack of satisfaction, 5 means complete satisfaction) of the IOS used for production planning in the company, the following answers were given:

- system response time/workload of scheduling – 4,
- alignment of the plan with production reality (planning effectiveness) – 4,
- system response to disruptions in the production process – 4,
- accessibility of data and information (response time, completeness) – 5,
- integration with other IT systems in the company – 5,
- alignment of available configuration variables with user needs – possibility to modify input parameters of planning, e.g., calendar – 4,
- intuitiveness/ergonomics of the scheduling interface – 4,
- recording the history of introduced plans and their changes – 3.

As can be seen from the respondent's answers, the results can be considered good and positively influencing the company's operations. The highest satisfaction ratings concerned data and information accessibility and integration with other IT systems in the company. The only exception to the good and very good ratings was the mid-scale score for the ability to record introduced plans and their changes.

The generalized evaluation of IOS (on a scale of 1 to 5, where: 1 means complete lack of satisfaction with the system's operation, and 5 means complete satisfaction) was rated as 4, which indicates almost full user satisfaction with the use of the IOS.

The overall (generalized) user satisfaction rating in the company "X2" increased from 3 to 4.

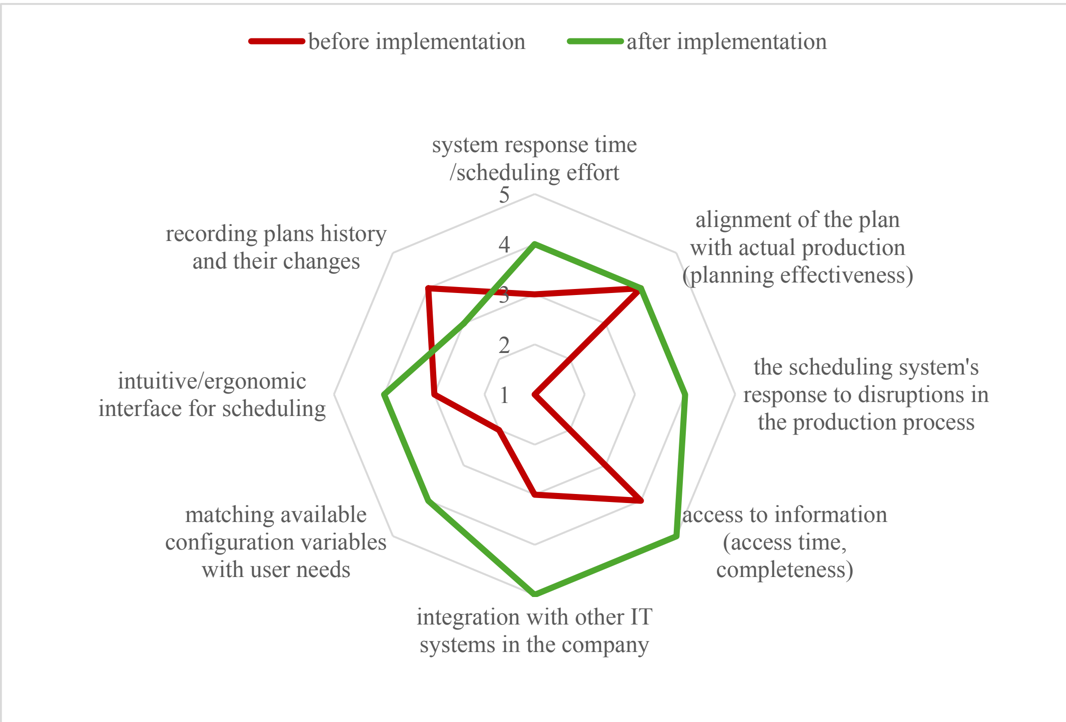

Figure 4. Comparison of X2 customer satisfaction ratings in selected areas before and after IOS implementation.

Source: own elaboration.

From the comparative analysis of customer satisfaction assessment elements in selected scored factors in the "before" and "after" states, an improvement can be observed in almost all evaluation parameters. The parameter "alignment of available configuration variables with user needs – the ability to modify input parameters" remained at the same level.

The parameter "recording the history of introduced plans and their changes" deteriorated.

This indicates a significant improvement in customer satisfaction in the company "X2" following the breakthrough innovation implemented in the IOS.

The generalized evaluation of user satisfaction in the company X2, on a 1-5 scale, is as follows:

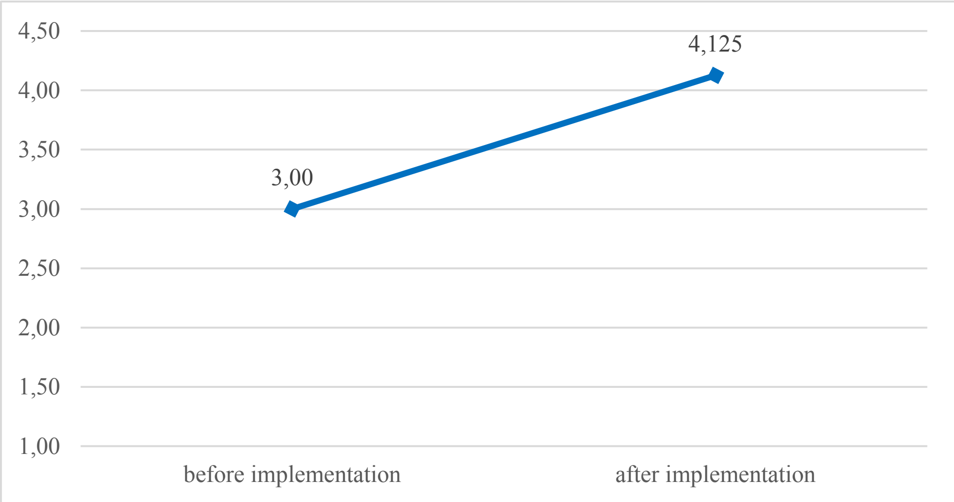

Figure 5. Comprehensive client satisfaction evaluation for X2.

Source: own elaboration.

If we compare the results obtained with other studies on the effects of optimization using genetic algorithm, we can point out that optimization is rarely the subject of satisfaction studies. The work by Ding et al. (2006) presents the effects of optimization in terms of reducing distribution costs. Of course, this leads to improved satisfaction, but the impact of costs on satisfaction is not direct. In addition, the authors point to an increase in end customer satisfaction (customers buying clothes). In our case, the end customers of companies X1 and X2 were not surveyed at all, although this could be an interesting topic for research. Similarly, in the article by Que et al. (2018), the effects of optimizing the production system include quality of service (QoS) components: time, reliability, cost, and ability. Satisfaction is a secondary effect that results or should result from achieving improvements in the hard elements of the production process.

4. Conclusions

The comparative assessment of the "before" and "after" states for the companies "X1" and "X2" with respect to selected parameters is as shown in the figure 6.

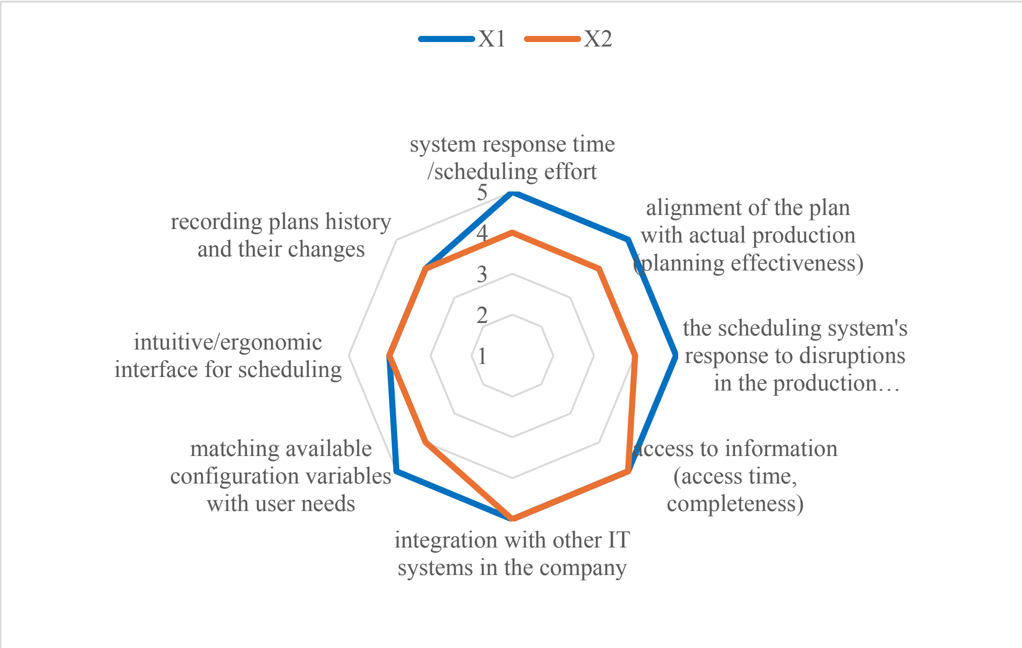

Figure 6. Customer satisfaction ratings in selected areas – clients X1 and X2.

Source: own elaboration.

It can be observed that for the company X1 the implemented innovation generates a higher level of user satisfaction in most of the analyzed parameters. However, the overall evaluation of the implementation in both entities is high, falling within the range of 4 to 5 on a 1-5 scale.

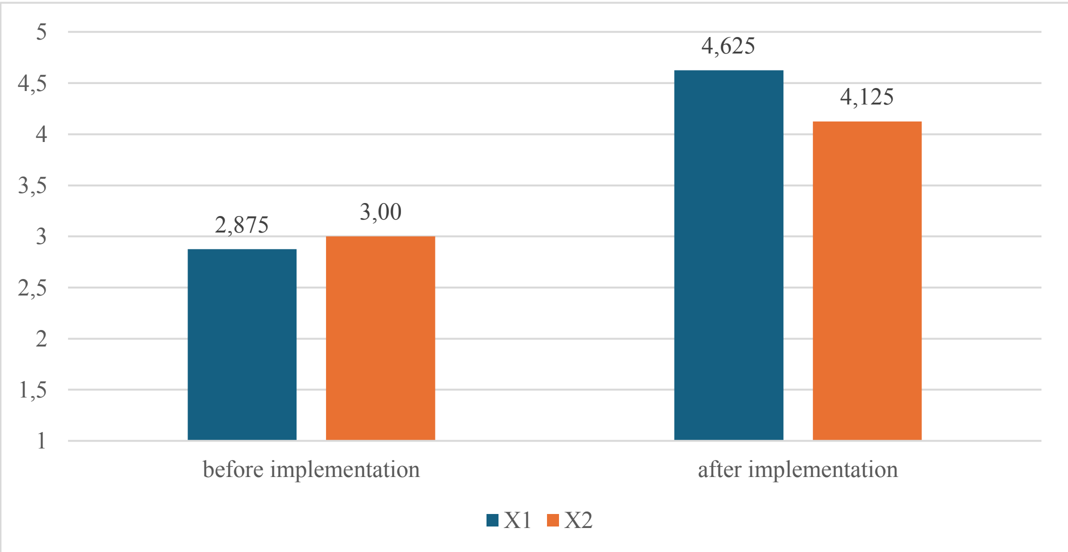

Figure 7. Customer satisfaction evaluation of X1 and X2 clients.

Source: own elaboration.

As we can see in Figures 6 and 7, the overall level of user satisfaction has increased. This means that users recognized the advantages of IOS, regardless of the effects it had in terms of reducing planned production time. The practice of users utilizing the scheduling system indicates that they are not seeking the ideal, shortest plan, but rather an accessible "good" plan that is feasible and can be quickly prepared in the event of production disruptions.

The research limitations for the presented issue concern conducting research in only two companies that tested IOS. The second research limitation relates to the short duration of the satisfaction survey during the ISO testing period. Further research will be necessary with a larger number of users and over a longer period of time, once those preparing production schedules have learned to fully utilize the functionality of IOS.

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