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PRODUCTION FLOW CONTROL IN AUTOMOTIVE INDUSTRY- QUICK SCAN APPROACH**P. Golinska¹†, M. Fertsch†, P. Pawlewski†**†Faculty of Computing and Management , Poznan University of Technology,
Strzelecka 11, 60965 Poznan, Poland**Abstract**

The automotive industry is highly competitive. Manufacturers have to effectively control very complex production process in order to fulfil on time customers' orders for customized cars. The automobile assembly plants are the high stabilized production systems. However, uncertainty is still inherent in such systems. The aim of the paper is to propose a method that might be applied for quick scan of the production flow in an assembly plant. The authors present briefly the theoretical background of the research and they discuss main problems that have appeared by analyses of the uncertainty influence on the manufacturing operations performance. The classification of disturbances sources is provided as well as the detailed description of the case study and numerical example.

Keywords:

production planning and control, disturbances, uncertainty, automotive industry.

1. Introduction

The production flow control in the automotive industry refers mainly to the monitoring of the planned production orders sequence and its maintaining within a given range of capability by feedback and correction. The control of the production flow comprises the following tasks: tracking vehicle flow in the production cycle, identification of serious setbacks on the production line, changing the vehicle sequence, issuing instructions for correction. The production flow control is performed based on the Master Production Schedule (MPS). MPS can be perceived as the main driver of information for production planning and control in MRP logic based systems. It can be treated as a benchmark for the ideal production flow. The car sequence that has been planned (in the MPS) serves as a pattern, and an attempt is made to maintain it in the course of production. However, when production orders start, their actual sequence deviates very often from the plan. Therefore, in order to make sure that the production is stable and delivered on time, it is particularly important to efficiently control the production flow.

Due to the complexity of the production systems in the production departments, different programs supporting the flow control are used. Computer programs help to visualize the vehicle sequence; however, often they do not generate solutions that optimize the production flow. The IT tools very often do not trigger alarms of changes, do not prompt any solutions to prevent changes in the sequence, do not offer suggestions how to change the vehicle sequence so as to maintain the stable MPS. According to the Motor & Equipment Manufacturers Association (MEMA), it takes approximately 3,800 different components (identified by unique part numbers) to build an average automobile. Many components, however, are used

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3 in multiplicities (e.g., car has five tires); thus, it takes nearly 35,000 separate items to build
4 each car. Without appropriate information on the real production orders sequence, it is
5 difficult to maintain the production on time and to synchronize all needed deliveries.
6 Companies often track an excessive and ever growing number of indicators to avoid missing
7 something important. As a result, a huge number of parameters is monitored by IT tools. It
8 causes the situation when production planners/controllers are overloaded with different data
9 and not able to analyze them on time.
10

11 A number of research works that have been conducted in the automotive industry, regarding
12 the improvement of the performance, concentrates mainly on material management within a
13 supply chain and integration of planning activities (e.g. Manson-Jones and Towill 1998,
14 Towill et al. 2002, Howard 2002).
15

16 The state-of-the-art studies conducted at the initial stage of this research project have shown
17 that there is a need to elaborate a set of simple indicators for a quick scan of the production
18 system. This quick scan should enable easy, on-hand evaluation of the sequencing activities
19 ongoing on the production floor. Moreover, the elaborated method should provide a simple
20 tool for the identification of potential serious disturbances that negatively affect the ability to
21 fulfil customers' orders on time.
22

23 In this paper authors identify the most important sources of uncertainty that appear in the
24 automotive industry and associate common disturbances with them. In the next sections the
25 main assumptions of the quick scan approach and its application in an automotive assembly
26 plant are discussed.
27
28

29 30 *1.1. Sources of uncertainty in high stabilized production systems planned by the MRP logic*

31 Traditionally in MRP systems both demand and lead times have been assumed to be
32 deterministic (Brennan and Gupta 1993). This assumption does not reflect the business
33 practice. In real-life manufacturing systems the production process is very often not executed
34 according to assumed MPS, because of the uncertainty conditions. Uncertainty can be defined
35 as any unpredictable event that disturbs the production process in a manufacturing system that
36 is planned by MRP (Koh and Saad 2003). Uncertainty is difficult to cope with, due to the lack
37 of foreknowledge resulting in problems with manufacturing system recovery on time.
38

39 The underlying causes of uncertainty, as well as the ways how they affect the manufacturing
40 system (based on MRP logic) were described by Koh et al. (2002). The researchers deployed
41 a system theory to structure uncertainty according to its source. In the above-mentioned
42 studies uncertainty was categorized into:
43

- 44 • input uncertainty – understood as uncertainty that occurs in external supplies and
45 external demand,
- 46 • process uncertainty – understood as uncertainty that occurs in internal demand and
47 internal supplies.
48

49 Brennan and Gupta (1993) identified the following sources of uncertainty:
50

- 51 • demand uncertainty – including forecast errors and changes in the orders placed by
52 customers,
- 53 • supply uncertainty – including both uncertainty connected with duration of process
54 lead times (production cycles) and delivery lead times.
55

56 Both of the above-mentioned categorizations can be combined into one. It can be assumed
57 that input uncertainty consists of external demand uncertainty (so called independent demand)
58 and delivery lead times uncertainty. Process uncertainty comprises internal demand
59 (dependent demand) uncertainty and process lead times uncertainty (production cycles).
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3 In this paper, the delivery lead times uncertainty is connected with all disturbing events that
4 cause the situation when a particular material/part is not available when needed. Authors do
5 not determine whether a particular delivery lacks appropriate quality (e.g. higher defect rate
6 than anticipated) or quantity (e.g. the quantity delivered by vendor was smaller than the
7 ordered quantity); in both cases this delivery is treated as delayed.

8
9 Lead times uncertainty is connected with all the disturbing events due to which a particular
10 technical operation cannot be executed on time e.g. lack of capacity, workforce absence, etc.

11 In the automotive industry, the uncertainty problem is especially harmful owing to the fact
12 that manufacturing systems are of high stability. The high stabilized production system
13 (HSPS) is characterized by (Golinska et.al 2006):

- 14 • steady production plans,
- 15 • Master Production Schedule (MPS) prepared many weeks in advance,
- 16 • high similarity of production routines,
- 17 • high similarity of product structure (BOM), however they may differ in the number
18 of specific attributes like for example colour,
- 19 • high automatization of operations,
- 20 • application of buffers to stabilize production process,
- 21 • low flexibility.

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28 Figure 1 presents the sources of uncertainty that appear in HSPS.

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Figure 1 goes here

Figure1. Source of uncertainty vs. level of stability

As presented in Figure 1, the high level of the production system stability allows for reducing the uncertainty of external demand and internal demand. It can be assumed that the only uncertainty to appear is that connected to delivery and process lead times. Such assumptions are based on in-field visits to factories and previous studies of other researchers. As a proof of such assumptions the studies conducted within the framework of the '3DayCar' program (Holweg and Jones 2003) can be cited. They show that in the European automotive industry, the forecasts of customers' demand regarding volume and item specification are prepared many months in advance. In order to protect the stability of their production system and the gain of economy of scale the manufacturers combine two policies by production planning, i.e.:

- build-to-forecast – according to average company standards, customers are served from inventories of final goods,
- build-to-order – a demand driven production approach that aims to provide vehicles built according to specification of individual clients in a minimal process lead time.

The automobile manufacturers very often apply "late-fit-strategy". It is an upgraded version of build-to-forecast strategy, whereby forecast orders are amended to customer requirements at the assembly line. Actual customer orders that are received are either fitted into the plan laid out by the production programmed months ahead, or the forecast orders in the system are amended to customer requirements. Due to the long planning horizon in the automotive industry, from the perspective of a production controller it can be assumed that the demand is deterministic.

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3 Internal demand uncertainty can be usually ignored in high stabilized production systems due
4 to the fact that they are high automated and all quality requirements are strictly kept. Quality
5 problems usually appear at the late phase of the production and they result mainly in reworks
6 that affect the production cycle duration. Due to a huge amount of added-value within
7 production process in automotive plants, the work-in-progress is very rarely denied by quality
8 control and classified as a scrape. As already mentioned, problems with the quality of parts
9 and components delivered by suppliers influence only delivery lead times (not internal
10 demand).

11
12 The previous studies on uncertainty in the MRP planned manufacturing systems, mainly
13 assume the modification of Master Production Schedule when a variation has appeared. The
14 high replanning frequency in order to overcome the uncertainty induces the system
15 nervousness.
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18 In HSPS the changes at MPS level should be avoided due to the fact that usually a fixed
19 number of orders is assigned to each production day/shift. Any changes in Master Production
20 Schedule result in the delays for the next production days. A crucial element of the effective
21 production flow control in the automotive industry is the identification of the disturbances.
22 Moreover, they should be identified as quickly as possible in order to avoid changes in MPS.
23 In the quick scan approach authors assume that all disturbances in the production flow should
24 be solved at MRP level.
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28 ***1.2. Dampening and buffering methods and techniques***

29
30 The effect of uncertainty has been examined by a number of researchers (Brennan and Gupta
31 1993, Guide and Shivastava 2000, Ho and Carter 1996). They propose techniques to tackle
32 uncertainty in the production system planned by MRP logic. These researchers examined a
33 variety of buffering or/and dampening techniques to minimize the effect of uncertainty. A
34 comprehensive literature review can be found in Guide and Shivastava (2000) or Koh and
35 Saad (2003). Based on the above mentioned studies, the authors of this paper identified the
36 buffering and dampening methods/techniques that might be applied in the high stabilized
37 production systems HSPS (see table 1). Cox and Blackstone (1998) defined buffering and
38 dampening techniques (BAD); they described buffering as a quantity of resource waiting for
39 processing (labour, money, machines). In their opinion dampening is based on planning
40 methodologies (e.g. rescheduling, safety lead time). Dampening techniques are understood
41 here as an information-based approach and buffering techniques are understood as an
42 application of resources-based approach (e.g. safety stock, safety capacity/overcapacity). In
43 Table 1 authors include the results of the assessment of the BAD techniques identified in the
44 cited work. As a criterion for assessment the level of stability is taken into consideration along
45 with sources of uncertainty that are typical in HSPS. Moreover, while making the assessment,
46 the authors took into consideration the results of interviews with shift managers at the
47 assembly plant. In their opinion, in the automotive industry, due to the high stability of the
48 production system, there is no intention to increase the number of buffers. Moreover, the zero
49 inventories approach is reflected in the continuous shift of safety stocks on the suppliers. Just-
50 in-time (JiT), just-in-sequence (JiS) deliveries are a standard approach in this industry. Taking
51 into consideration all of the above-mentioned factors, it can be assumed that dampening
52 techniques are more appropriate than buffering techniques in this sector.
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57 In table 1 authors present only these BAD techniques, which in their opinion might be applied
58 for HSPS; herby, they are indicated there as the modification of the previous research.
59
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Tab.1. BAD with application potential in HSPS modified from (Koh et al. 2002)

Tabele 1 goes here

2. Automotive Industry – Production Planning and Control

The production process in the automotive industry can be divided into three technological phases: body welding, painting, final assembly. The simplified schema of a production system is presented in Figure 2.

Figure 2 goes here

Figure 2. Production system model

The production system typical for the European automotive industry is a mixture of the traditional mass production features in the departments responsible for pre-treatment (D1, D2) and lean (for more see Womack et al. 1991) concept in the area of the final assembly (D3).

In the European automotive industry production scheduling is prepared 2-3 weeks before production starts. Orders are picked from the order bank and are assigned to production weeks at different plants. The scheduled orders for a build week are re-shuffled into a sequence of build orders for the assembly plants. In any case, only after the orders are sequenced, the suppliers actually receive their final call-off of what is required, as only then it is actually defined what parts will be needed (Holweg and Jones 2003). Sequenced orders are sent to the body shop (welding department). The paint shop is the bottleneck of the production process by the most of manufacturers. In order to improve the efficiency of painting operations, after the body shop, car bodies are accumulated in pre-paint buffers. When the minimal required amount of car bodies is collected, they are to be sprayed in the same colour. In the paint shop, the initial planned production sequence is usually distorted and becomes unpredictable for all subsequent assembly operations. After paint, the cars are generally re-shuffled again before they are sent to the assembly department. It is done to ensure the mix of cars needed for the line balancing activities. In practice, this reshuffling activity causes a lot of problems due to common variations in the duration of painting lead times. A big number of reworks is often required at the paint shop due to the common failures of the painting process (usually undesired objects/materials glued to the fresh paint coat or uneven paint coat). It is very difficult to forecast the real length of the production cycle for particular orders. This uncertainty inherent in the process lead times at the paint shop causes many problems, so that reshuffling operations before assembly line cannot be completed on time.

The line balancing approach leads to a need for a precise control of the production flow and quick response in a situation when the real production sequence is disturbed and differs from the assumed plan. At the same time, in case of automotive industry where just-in-time and just-in-sequence deliveries are common, business practice changes that appear in Master Production Schedule result in problems with on-time customer's orders fulfilment. Manufacturers often fail to deliver the right product within an acceptable timeframe to the customer.

Changes in Master Production Schedules (MPS) result in due-date changes in open orders, quantity and timing for planned order of end products. The above-mentioned changes are being translated into gross requirements changes for components and timing of their delivery. It leads to the situation when materials needed for a particular order may not be available particularly if there is an increase in ordered quantity and shortened due date. This situation is

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3 especially harmful for just-in-sequence deliveries when all the parts/components are delivered
4 directly to the assembly point in the exact sequence. Each part is placed in a container in the
5 particular sequence and signed with VIN number (vehicular identification number) of a
6 automobile in which it is supposed to be mounted. Good examples of JiS deliveries are
7 mirrors, which are prepainted before assembly, so a silver mirror goes to a silver car, a red
8 mirror to a red car etc. Any disturbances, which cause variations in the production sequence,
9 should be immediately announced to the suppliers. Otherwise, materials needed for a
10 particular order may not be available or an unwanted delivery might appear, like for example
11 arrival of the parts that are not needed any more at the particular production shift. Both
12 situations affect the organization of the production flow.
13
14

15 16 17 **3. Disturbances in production system**

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19
20 The uncertainty conditions combined with the complexity of a production system increase the
21 risk of disturbance appearance. Disturbance can be defined as an unexpected and unplanned
22 event, which causes the deviation between planned Master Production Schedule MPS and real
23 production flow (production sequence) within the production system. The deviation between
24 the initially planned and real production sequence resulting from intentional planner activities
25 (e.g. change of the initial order priority) will not be treated as a disturbance. Disturbances in a
26 production system can differ a lot: e.g. breakdown of machines, serious delay in deliveries,
27 workers absence. The disturbances can be classified based on two criteria:
28

- 29 1. source of disturbance,
- 30 2. effects they have on the production system.

31
32 Taking into consideration the first criterion, the following types of disturbances (after Lis
33 1982) are determined:

- 34 • disturbances of the production resources: breakout of machines and tooling, absence
35 of the workforce,
- 36 • disturbances of the production systems inputs: shortages of materials and energy,
37 invalid external services, lacking information or data, financial factors.

38
39
40 Based on the second criterion the following types of disturbances can be identified (after
41 Patig, 2001):

- 42 1. production control goal disturbances,
- 43 2. production capacity disturbances,
- 44 3. input disturbances,
- 45 4. information flow disturbances.

46
47 The main goal of the production control is to execute the production flow according to the
48 planned MPS. The disturbances of the production control goal are any deviations in the initial
49 MPS execution appearing at an independent demand level caused by changes in customers'
50 demand or customers' order due dates.
51

52 The production capacity disturbances are any variations in the initial MPS execution caused
53 by a limited availability of production resources (machines, tooling, and workforce). These
54 disturbances appear at the MRP level. The input disturbances are any variations in initial MPS
55 execution appearing at dependent demand level caused by shortages of raw materials. The
56 input disturbances are any variations in initial MPS execution appearing at dependent demand
57 level, caused by inappropriate information and data on the technology: e.g. outdated Bill of
58 Material, invalid data on maintenances, lead times, and inventory levels.
59

60 Due to the deterministic demand assumption, only disturbances appearing at MRP level are
taken into consideration in the proposed quick scan approach.

4. Quick Scan Approach

The effective production control requires the appropriate mechanisms for the process flow monitoring and its normalization when fluctuations appear. The scope of fluctuations in the production flow caused by disturbances very often is bigger than the buffering abilities of the manufacturing system. The protection of the initial sequence of production orders (production flow) is essential because the main value adding activities take place at the final assembly department. Most of the automobile manufacturers apply Just-in-Time/Just in Sequence delivery schema at this part of the production process. Inefficient production flow control results in delays in customer's orders fulfilment. Quick scan approach helps to reduce the process lead time uncertainty by speeding-up the information feedback loop.

The model for production planning and control in an automobile plant is presented in Figure 3. The final assembly schedule (FAS) is prepared on the basis of MPS usually 2-3 weeks before production due-date. It shows in detail the production sequence for every day (per production shifts). The FAS depends on company capacities constraints (e.g. max 50 automobiles with automatic gear per shift, at least 4 automobiles in the same colour per block etc.) and availability of materials. These schedules are also sent to suppliers and discussed with them. The FAS is supposed to be executed to the unit. It can be observed that in real life almost in every shift some variations in FAS appear. Due to the production system complexity, there are problems to identify the sources of disturbances. On the basis of the case study and the literature review authors elaborated an approach for quick scan based on a few simple indicators.

Figure 3 goes here

Figure 3. Model for production planning and control (information loops)

This approach is based on the assumption that due to the low flexibility of the production control system, it is crucial to build up quasi-flexibility into the production system. There are four elements of a production control system determining its total flexibility, namely (modified from Patig 2001):

- flexibility of a production control goal – understood as an ability to easily change MPS at any time,
- flexibility of production resources – understood as a possibility to substitute machines (e.g. overcapacity, alternative machines on hand, multi-skilled workforce etc.),
- flexibility of production programmes – understood as a wide portfolio of products that can be produced at the same production line,
- flexibility of production operations – understood as a possibility to manufacture the same product in a number of alternative ways/routines.

The flexibility of a production control goal in HSPS is very limited. The other three components of flexibility, namely production resources, production programmes and production operations, determine the alternative decision variants for the production planner/controller's. The alternative decision variants should ensure the execution of the same production control goal (the same MPS in the defined time-framework). Simultaneously, the choice of a particular decision variant results in the appearance of particular events. One choice is determining the new alternative decision variants that are still available as the follow-up actions. The availability of appropriate control information as soon as possible, allows the controller to choose these decision variants (potential corrective actions) that

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3 provide the lowest deviation between the real MPS and the planned MPS. It can be assumed
4 that the flexibility of a production control system is a space of alternative decision variants,
5 which afterwards can be transformed into corrective actions. In order to reach the quasi
6 flexibility of a control system in the conditions of HSPS, it is crucial to shorten the time
7 between the appearance of events and the time when this information is visible for the
8 controller/planner. The availability of appropriate information (regarding identification of
9 disturbance) allows a quick application by feedback loop corrective actions into the
10 production flow. It is important because a quick assessment of the real production flow
11 (sequence) allows choosing the best corrective action variants.
12
13

14 Figure 4 presents the production model that is applied in the quick approach. The production
15 system in the automotive industry is monitored usually by a number of scanners that register
16 the data from bar codes/GS1, codes which are plugged to any car body at the beginning of the
17 production process. The places where scanners are located can be called production control
18 points (PCPs). A number of PCPs differs among particular manufactures. The data from PCPs
19 is sent in real time to production databases. The initial production MPS is divided into orders
20 block. The size of a block can differ and depends on individual features of particular cars.
21 Each car is indicated in the production system as POIN (Production Order Identification
22 Number). The production flow should be executed according to the planned MPS. In the
23 production database, data is stored on the times when particular POINs reach particular PCPs.
24 Based on this information, the third part logistics companies (3PLCs) and the first trier
25 suppliers release their delivery schedules. Any unidentified disturbances in the production
26 flow result in problems with on time deliveries.
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29

30 **Figure 4 goes here**

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33
34 Figure 4. Quick scan – production system model

35 The structure of data depends on a particular company. It can be assumed that the minimal
36 requirements for data needed to apply quick scan approach are (Table 2):
37

- 38 • (POIN)
 - 39 • PCP identification code
 - 40 • date
 - 41 • time when particular POIN passes through particular PCP
- 42
43

44 Tab.2. Simplified structure of database (Golinska et al. 2009)

45 **Tabele 2 goes here**

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48
49 The authors propose defining and implementing an information feedback mechanism, relying
50 on a quick, automated measurement of sequence and pre-defined initial conditions triggering
51 appropriate corrective actions in response to a sequence change.

52 This quasi flexibility of the production control system can be achieved by decreasing the time
53 between appearance of a disturbance within the production process and the moment when this
54 information is available for the controller not as a pure data but as a diagnosis of the
55 production flow problem (control information feedback). This is presented in Figure 5.
56
57

58 **Figure 5 goes here**

59
60 Figure 5. Quick scan – production flow control model

As presented in Figure 5, disturbances can be monitored and afterwards can be classified into two categories:

- serious disturbance – when a variation between planned and real sequence is bigger than buffering abilities of the production system,
- the danger of serious disturbance – when the appearance of a disturbance in nearly future can be forecast.

The production flow control model (Figure 5) follows the procedure:

1. Define the block of orders,
2. Observe the defined block of orders and assess the production sequence,
 - a) count the OPS indicator value for a block of orders,
 - b) compare it with the critical value of OPS indicator,
3. If the production sequence is disturbed (the value of OPS for a defined block falls below the critical value), analyze the production flow cycle for this block (indicator $PFC_{set_{av}}$) at this PCP,
4. Identify the type of disturbances based on the assessment of a production sequence and production flow indicator,
5. Choose suitable corrective actions and apply them at MRP level,
6. When corrective actions cannot be applied at MRP level, inform the production planner,
7. When necessary, adjust the MPS (redefine the next blocks).

The above-presented simplified procedure is a continuous process that can be automatically executed for the whole production flow. The indicators, which are used in the procedure, are described below. As mentioned in the previous sections of this paper, changes in the MPS should be avoided and all corrective actions should be taken at MRP level.

The quick scan approach is based on following indicators:

- Production flow cycle indicator PFC – is counted as a sum of time periods that the analyzed Production Order Identification Number (POIN) needs to pass the following production control points PCPs (equitation 1). The time when POIN enters the production system at PCP1 is counted as 0 ($t_{pcp1} = 0$):

$$PFC = \sum_{i=1}^n t_{pcpi} \quad (1)$$

This indicator is used in order to observe the duration of a production cycle (process lead times) for the particular production order POIN. It also allows finding the particular configuration of car attributes (configuration of components) that has an extraordinary long production cycle and might cause delays in the production flow.

- For a block of k number of POINs the indicator is counted as (equitation 2):

$$PFC_{set_{av}} = \frac{\sum_{k=1}^k POIN_k \sum_{i=1}^n t_{pcpi}}{k} \quad (2)$$

In order to define the typical and critical values of the production flow cycle indicator for a block of POINs, on the basis of a long-time observation of non-disturbed POINs (with the same key features as analyzed block), the “ideal” values are counted based on equitation 2 and named as $PFC_{set_{av}ID}$.

- Sequence dispersion range (SDR) – measured for a block of POIN as a difference between maximum order identification number in a defined block and minimum identification number observed at a chosen production control point (equitation 3).

$$SDR = (POIN \text{ max} - POIN \text{ min}) \quad (3)$$

The value of SDR indicator shows how a block of POINs defined in the initial MPS was distorted by the appearance of a number of POINs belonging to other blocks of orders.

- The overall production sequence indicator presents the number k of POIN in the analyzed block to SDR at an observed production control point, for example if there was “ k ” POIN and the SDR equals to “ k ”, the quality of operations management regarding sequencing is 100%. The value of this indicator is counted as following (equitation 4).

$$OPS = \frac{k}{SDR} * 100\% \quad (4)$$

The low value of OPS indicator informs about a serious disturbance in the production flow for the analyzed block. On the basis of the proposed indicators, it is possible to monitor the production flow and to identify when serious disturbances appear and regulatory activities are needed.

Based on the interviews with the shifts managers, the typical disturbances in the production flow were identified, as presented in Figure 6 (step 4 of the procedure).

Figure 6 goes here

Figure 6. Examples of typical disturbances in an automobile plant

The above-mentioned problems were transformed into the types of disturbances categorization presented in Section 2. Only types of disturbances that appear at the MRP level are taken into consideration, because demand is assumed to be deterministic (Tab. 3).

Tab. 3. Identification of the type of disturbances

Tabele 3 goes here

5. Numerical example

The numerical example presents the application of the proposed quick scan approach. The procedure described in the previous section is implemented. In step one the block of 16 orders (cars) is defined. In step two the production sequence is assessed, so OPS indicator is calculated for this block (Table 4). The following PCPs are taken into consideration:

- MPS – system entry, the sequence is equal to initial MPS
- B1, B2 – body shop (1) entry and (2) exit
- P1, P2 – paint shop (1) entry and (2) exit
- A1, A2 – final assembly (1) entry and (2) exit
- FC – final control

The number of PCPs can be individually defined by a particular company (without affecting the effectiveness of the proposed quick scan approach).

Tab. 4. OPS indicator for a defined block in [%] – ex post

Tabele 4 goes here

Tab. 5. OPS indicator, average values and critical values for the analyzed production system in [%]

Tabele 5 goes here

The next step in the assessment is the comparison of the calculated OPS with its critical value. The critical value is individual for each company. It is calculated as an average value of OPS indicator for this PCP (long-term calculation for a defined period)) minus the tolerance value. The value 25% used in this numerical example was defined based on interviews with shifts managers in the analyzed company and statistical analyses of the production data for a defined period.

The value of OPS indicator equals 100% when the production flow is not disturbed. For the analyzed block (Table 4) it can be observed that the flow of production is seriously disturbed (below the critical value, Table 5) at the body shop and paint shop. At the final assembly department the production sequence (production flow) is finally undisturbed (after corrective actions), but at the end of the production process the sequence is again disturbed.

Following the quick scan procedure described in Section 4, when the value of OPS falls below the critical value, the analysis of indicator the $PFC_{set_{av}}$ at this PCP is needed. In order to calculate the benchmark for its duration, the first indicator the $PFC_{set_{av}}$ is counted for the so called ideal block of orders ($PFC_{set_{avID}}$) and then the tolerance is defined. The tolerance value is individual for each company.

Tab.6. $PFC_{set_{avID}}$ indicator for block of orders (the 'ideal values' ID)

Tabele 6 goes here

Figure 7 goes here

Figure 7. PFC indicator for defined block

As presented in tables 4 – 6 and in Figure 7 the low values of OPS at PCP from B1 to P1 are not followed by the increase of PFC indicator over the critical value. Based on Table 3, it can be assumed that the production sequence is disturbed by:

1. machine breakdowns at the parallel part of the production line,
2. non-standard material requirements,
3. non-standard supply lead times,
4. poor quality,
5. lack of needed components,
6. invalid BOM.

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3 The disturbances caused by a non-standard production can be eliminated (2-3) due to the
4 block size. According to the company's organizational rules, the block of non-standard
5 production orders cannot be bigger than 6 POINs. In case of poor quality (4), at this
6 production phase, the orders have to be re-processed so that the production flow indicator
7 would increase. Invalid BOM (6) disturbs the production flow at the final assembly, not at the
8 body and paint shop. The only possible causes of deviations are machine breakdowns at a
9 parallel part of the production line and the lack of needed components. In order to fully
10 identify the cause, a quick interview with production shift management of a particular
11 department is needed.
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14 At the production control point P2, the value OPS indicator falls below 5%. In most of the
15 European automotive companies orders are reshuffled at the paint shop to build up particular
16 colour blocks. For orders no. 8, 9, 10, 14, the production flow cycle indicator increases over
17 the critical value. Based on the data presented in Table 3, it can be assumed that disturbances
18 in the production sequence are potentially caused by:
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- 20 1. non-standard supply lead times,
- 21 2. poor quality,
- 22 3. lack of needed components.

23 As mentioned before, the non-standard production can be excluded. All chemicals used at the
24 paint shop are rather standard and repetitive, so shortages of paint or other chemicals would
25 cause delays of a bigger number of POINs (PFC indicator over critical value). It can be
26 identified that disturbances in the production sequence between P1 and P2 (at the paint shop)
27 are caused by poor quality. The paint shop is usually a bottleneck in a number of automotive
28 companies. The peculiarity of the paint process leads to a big amount of failures that need to
29 be reprocessed, e.g. not appropriate paint coat, workers' hairs or fibres from clothing stuck to
30 the paint coat.
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34 The quick identification of disturbances based on a quick scan approach allows the production
35 controller to take the appropriate corrective actions. The value of the OPS indicator comes
36 back to 100% at the final assembly department (A1-A2) and no disturbances are identified. At
37 the production control point FC, the OPS value falls again a bit but not below the critical
38 value. It is a place in the production system where the technological process is finished and a
39 car is ready to be tested. As presented in Figure 7, some cars (POIN 11&15) need to be
40 reworked; the time-consuming re-processing is illustrated by the increase in PFC at A2-FC
41 part of the production system.
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44 The type of production flow disturbance can be found out as soon as possible by the
45 observation of only 2 main indicators (OPS and PFC). Such an approach accelerates the
46 process of production flow control and helps to take appropriate corrective actions. Moreover,
47 the production planners are not overloaded with information (they do not need to monitor
48 many parameters). The uncertainty of deliveries lead times and process lead times is reduced.
49 This reduction is achieved by the improved monitoring of the production flow. Most of the
50 unpredictable events that disturb the production process can be identified based on the OPS
51 and PFC indicators, so the variations in the production flow can be easily identified and
52 corrected before they are too big to be fixed at the MRP level and the adjustment of MPS is
53 needed.
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58 8. Conclusions

59 The automotive production system is very complex. Under the pressure of time, it is very
60 often difficult to analyze the production database in order to identify disturbances. The paper

presents quick scan approach that can be applied in the European automotive industry. The proposed approach is designed as a help for production controllers in order to easily exclude some of potential types of disturbances by means of observing a few simple indicators. In order to apply this method, the knowledge about the production system, organizational conditions and the main design characteristics, as well as typical disturbances are required. The future research works should enhance the implementation of the proposed indicators into the information management system for production aimed at a continuous (on-line) monitoring of the production plans execution. Also some heuristic methods are needed to define the critical values of the proposed indicators. The presented research is strongly case-oriented. However, due to the fact that manufacturing systems of the European automotive manufacturers are very similar, the proposed solution might be applied to other companies in the sector as well.

REFERENCES

- Brennan, L., and Gupta, S.M., (1993), A structured analysis of material requirements planning systems under combined demand and supply uncertainty, *International Journal of Production Research*, vol. 31, pp. 1689-1707.
- Cox. J.F., Blackstone J. H., (1998), *APICS Dictionary*, 9th ed. (VA. USA: APICS, The Educational Society for Resource Management).
- Golinska P., Fertsch M., Oleskow J., Pawlewski P., (2006), A model for production flow control in a machines assembly plant in conditions of process lead times uncertainty [in:] *Proceedings of The Flexible Automation and Intelligent Manufacturing International Conference (FAIM 2006)*, Limerick, Ireland, 25-27.06.2006.
- Golinska P., Fertsch M., Pawlewski P., (2009), Quick scan of the production system for disturbances, [in:] *Proceedings of The Flexible Automation and Intelligent Manufacturing International Conference (FAIM 2009)*, Middlesbrough, UK
- Guide V.D.R., Shiverasta R., (2000), A review of techniques for buffering against uncertainty with MRP systems, *production, Planning and Control* vol. 11, pp.223-233.
- Ho, C.J., and Carter, P.L., (1996), An investigation of alternative dampening procedures to cope with MRP system nervousness, *International Journal of Production Research*, vol. 34, pp. 137-156.
- Howard M. (2002), 3DayCar Production Flexibility: Solving the barriers to production and process technology in a build-to-order environment, 3DayCar Program Internal Report.
- Holweg M., Jones D.T., (2003), The challenge of building cars to order, can current automotive supply chains cope?, <http://www.3dayscar.com>.
- Koh L.S.C., Saad S.M., (2003), How Uncertainty Disturbs SME Manufacturers, *Proceeding of 17th ICPR*, Blacksburg, Virginia, USA.
- Koh L.S.C., Saad S.M and Jones M.H, (2002), Uncertainty under MRP-planned manufacture: review and categorisation, *Journal of Production Research* vol.31, pp. 2399-2421.
- Mason-Jones R., Towill D.R., (1998), Shrinking the Supply Chain Uncertainty Circle, 'Control', the *Journal of the Institute of Operations Management*, vol. 24 no. 7, pp. 17-22.
- Lis St. eds., (1982), *Rytmiczosc procesu produkcji, zakłócenia i ich kompensacja*, PWE, Warszawa.
- Patig S., (2001), *Flexible Produktionsfeinplanung mit Hilfe von Planungsschritten*, PhD thesis, Uni. Magdeburg.
- Towill D.R., Childerhouse P., Disney S.M. (2002), Integrating the Automotive Supply Chain: Where are we Now?, *International Journal of Physical Distribution and Logistics Management*, vol. 32, no. 2, pp. 79-95.
- Womack J.P., Jones D.T., Roos D., (1991), *The machine that change the world, the story of lean production*, Harperperennial, N.Y.

Tab.1. BAD with application potential in HSPS modified from (Koh et al. 2002)

Uncertainty Type	Source of uncertainty	Buffering	Dampening
Input uncertainty	Delivery lead time (external supply)	Safety stock	Safety lead-time Lot sizing rules
Process uncertainty	Process lead time (internal supply)	-	Process-lead time adjustment
Hybrid uncertainty	Delivery lead time & process lead time (external supply & internal supply)	Safety capacity at non-constraint Safety stock	Scheduling lead time Pegging Dynamic delivery lead time management

Tab.2. Simplified structure of database (Golinska et al. 2009)

Production sequence /PCP	PCP 1	PCP 2	PCP ...	PCP N
POIN 1	Date, Time	Date, Time	Date, Time	Date, Time
POIN 2	Date, Time	Date, Time	Date, Time	Date, Time
...	Date, Time	Date, Time	Date, Time	Date, Time
POIN N	Date, Time	Date, Time	Date, Time	Date, Time

Tab. 3. Identification of the type of disturbances

Effects caused in production system by disturbances	Fall of OPS indicator under critical value (a)	Growth of PFC indicator over critical value (b)
Production capacities disturbances	– machines' breakdown at the parallel part of the production process	– breakdown of information systems, – breakdowns of electricity systems – machines' breakdown at the joint section of the production process
Input disturbances	– non-standard material requirements	---
	– non-standard delivery lead times, – poor quality, – lack of needed components (delays in external supplies – delivery)	
Information flow disturbances	– invalid production data (mainly invalid BOM)	– changes in design of product, – non-standard design

Tab. 4. OPS indicator for a defined block in [%] – ex post

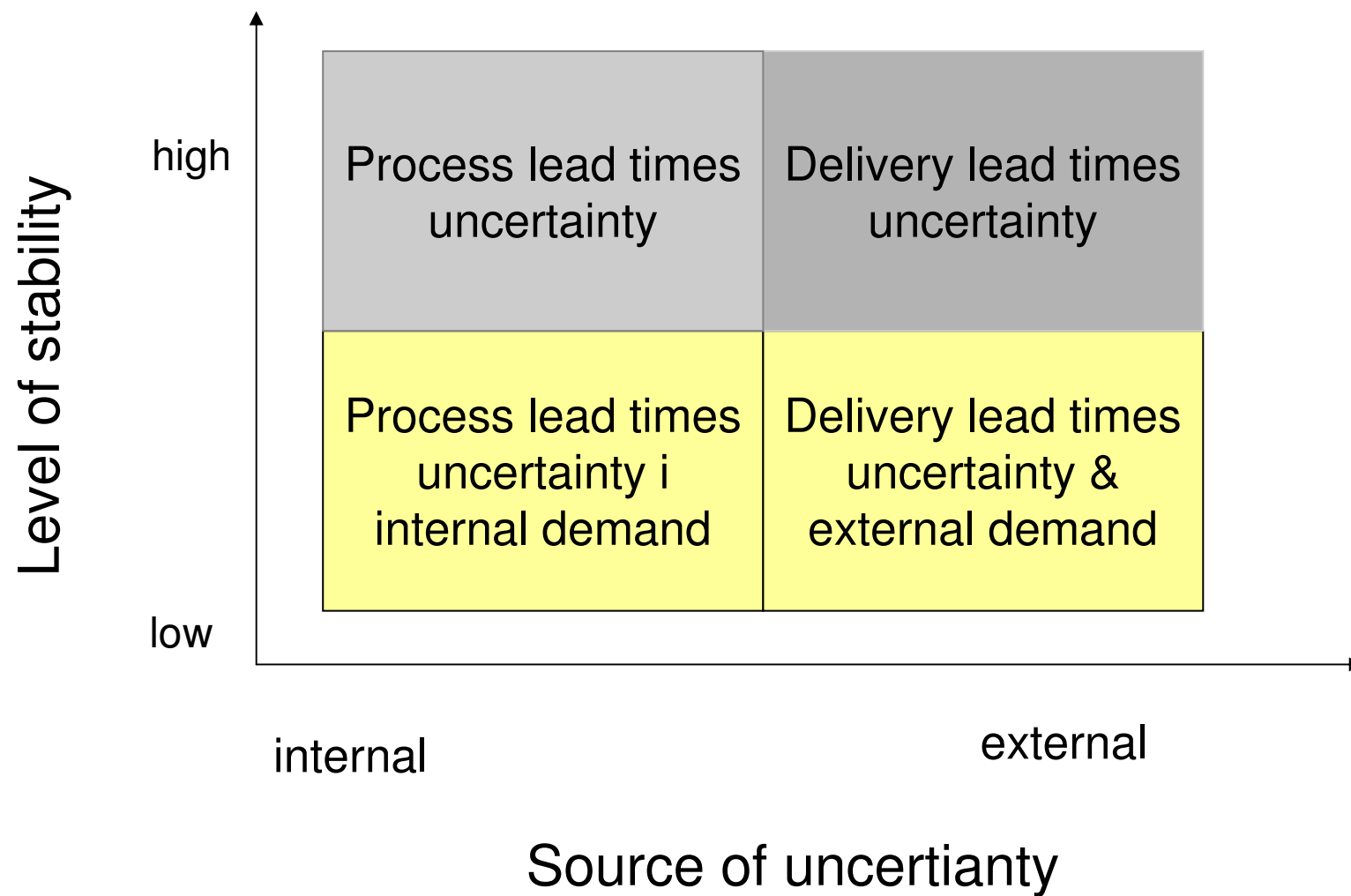
	MPS	B1	B2	P1	P2	A1	A2	FC
OPS	100,00	27,78	20,21	20,83	4,53	100,00	100,00	84,45

Tab. 5. OPS indicator, average values and critical values for the analyzed production system in [%]

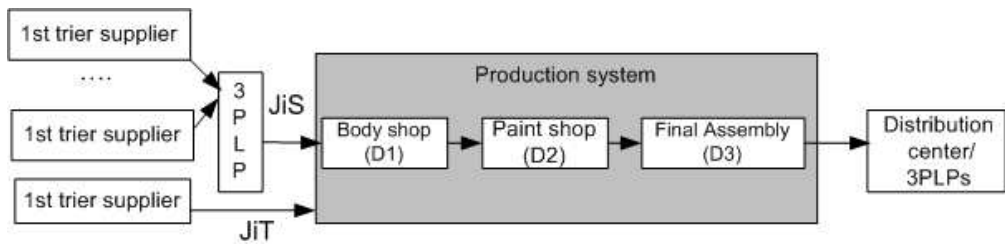
	MPS	B1	B2	P1	P2	A1	A2	FC
OPSQ av.	100,00	63,93	42,05	37,04	46,35	47,47	47,88	60,36
Tolerance 25%	0,00	15,98	10,51	9,26	11,59	11,87	11,97	15,09
critical value	100,00	47,95	31,53	27,78	34,76	35,60	35,91	45,27

Tab.6. PFC_{set_{avID}} indicator for block of orders (the 'ideal values' ID)

	MPS -B1	B1 -B2	B2 -P1	P1 -P2	P2 -A1	A1 -A2	A2 -FC
PFC _{set_{avID}} [h]	22,49	23,75	29,31	45,91	49,59	59,15	69,82
Tolerance [h]	2,25	2,38	2,93	4,59	4,96	5,92	6,98
Critical value [h]	24,74	26,13	32,24	50,50	54,55	65,07	76,80

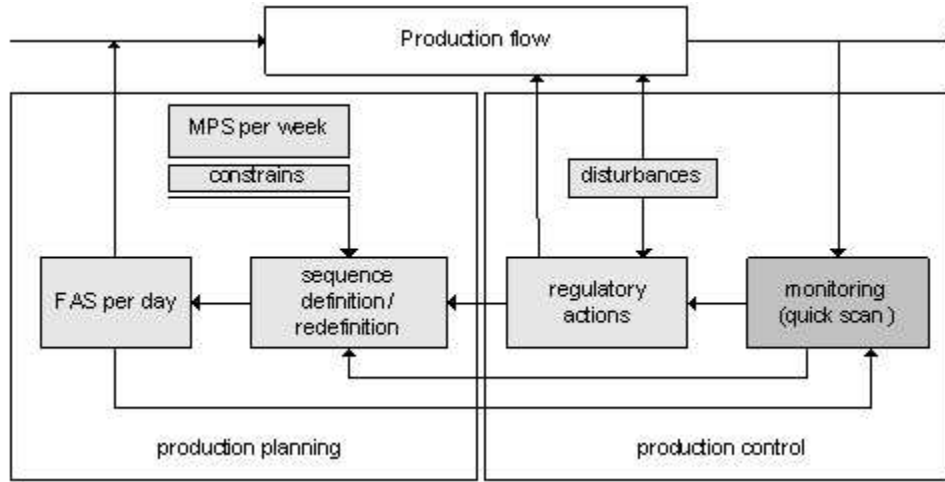


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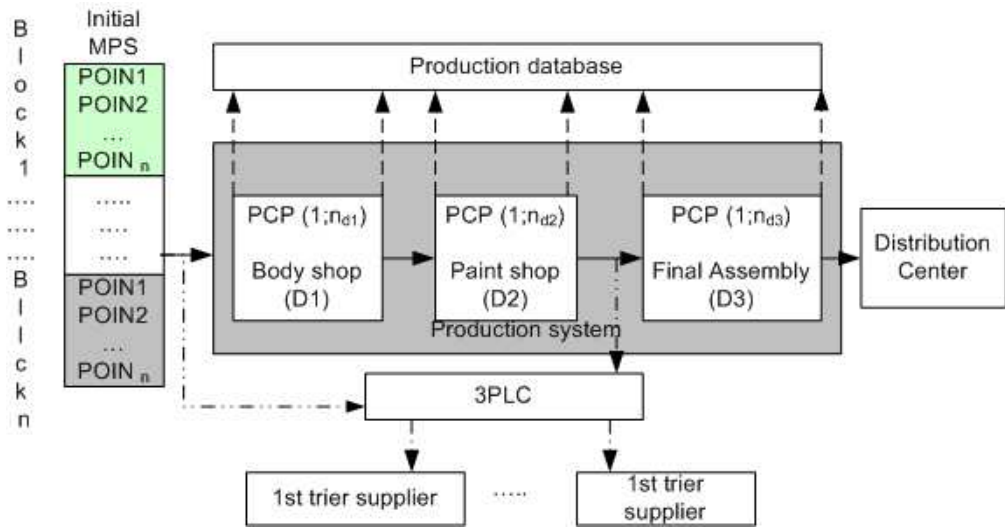


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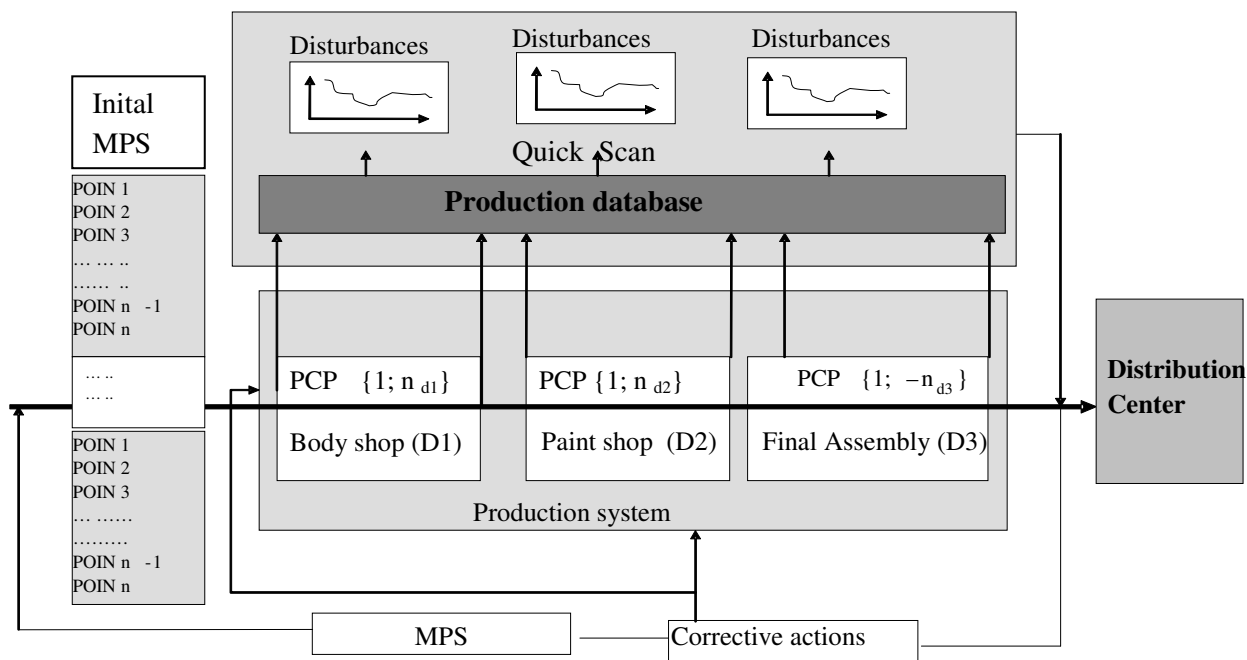
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Appendix

1. Define the block of orders

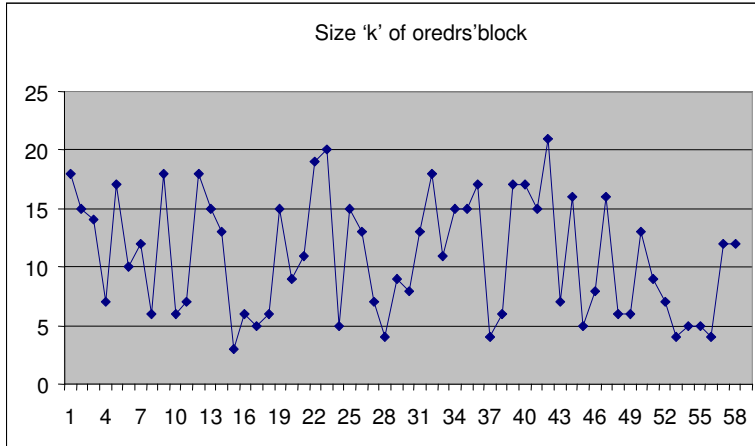
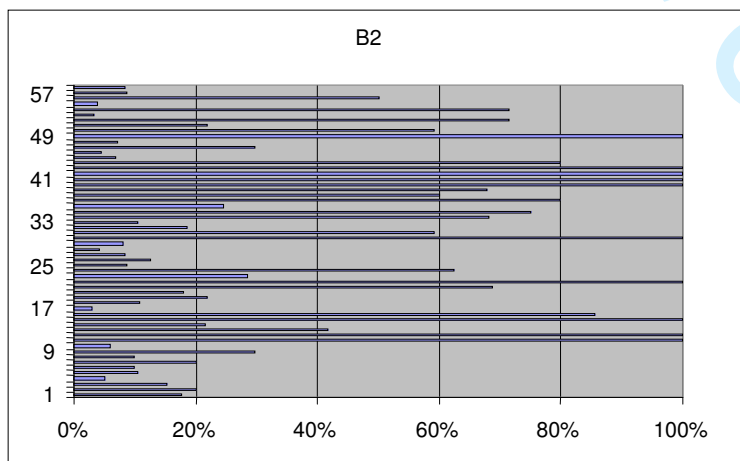
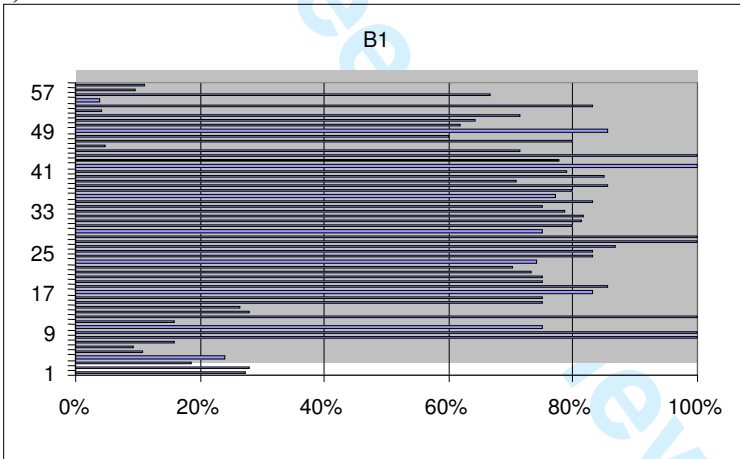
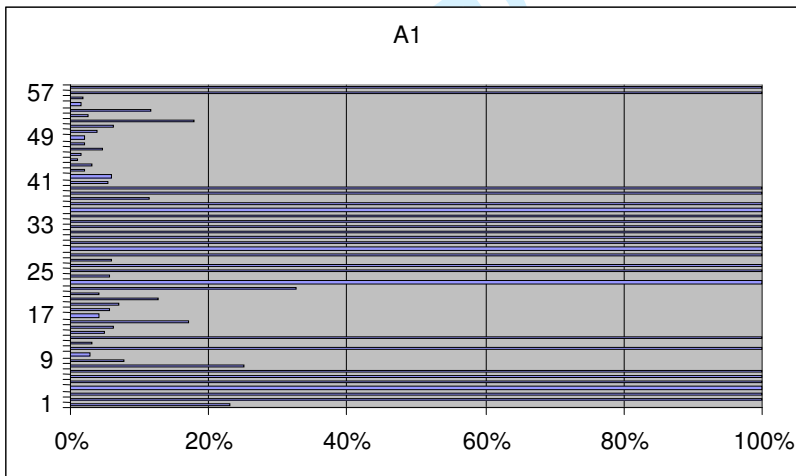
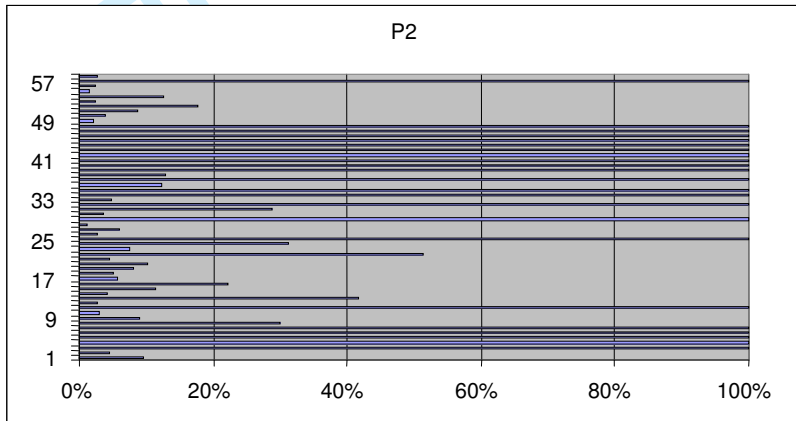
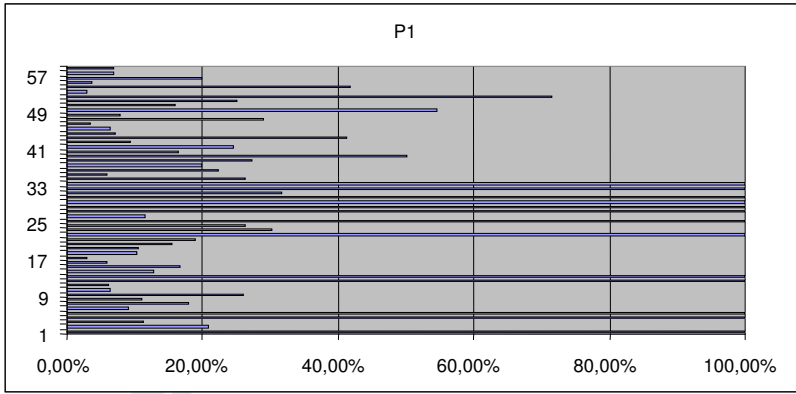


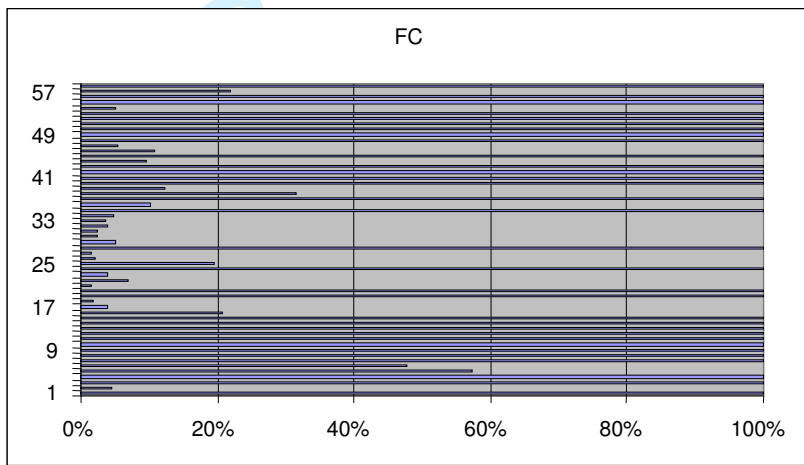
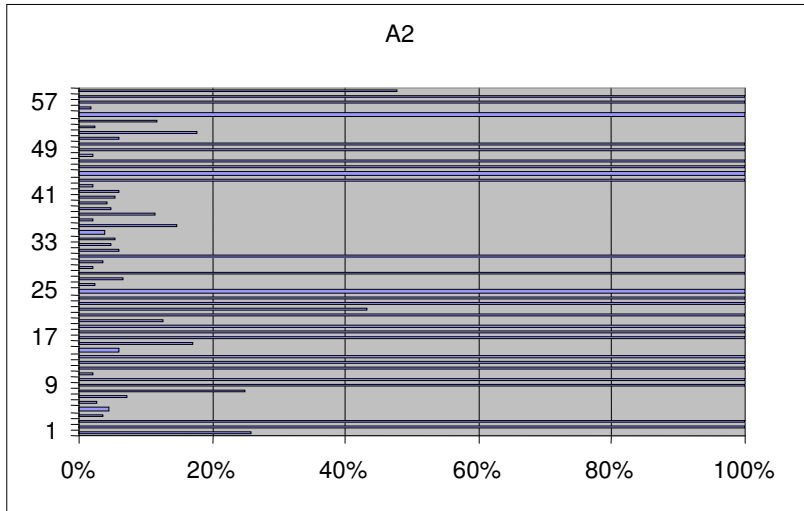
Fig.A1 Size “k” of the block of orders depending on work consumption at the assembly line

2. Observe the defined block of orders and assess the production sequence

a) Count the OPS indicator value







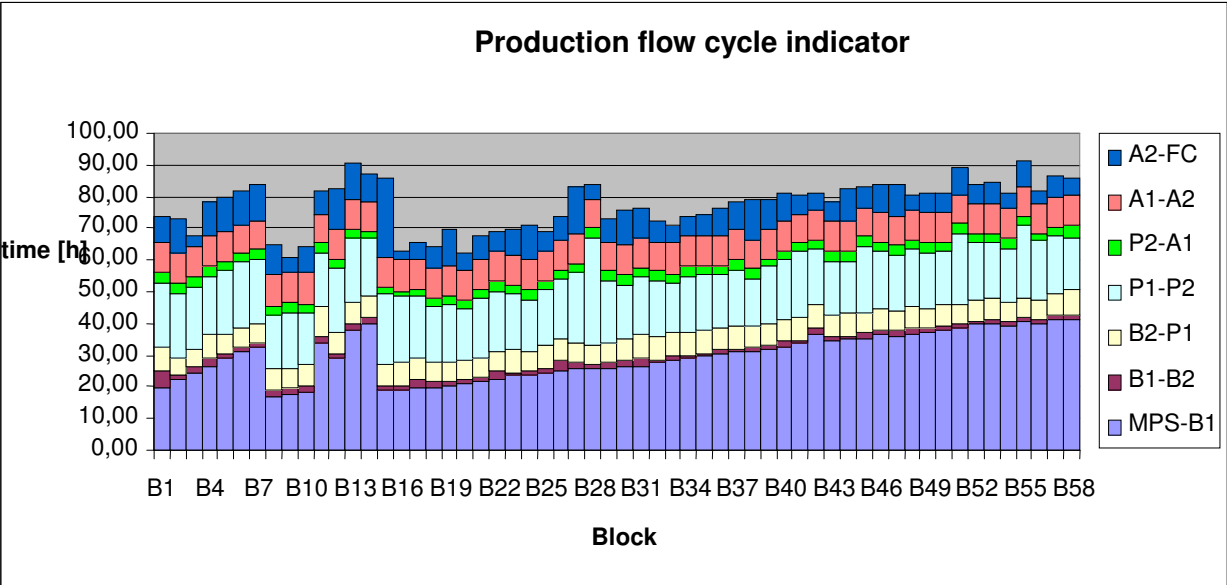
b) compare it with the critical value of OPS indicator

BLOCK	MPS	B1	B2	P1	P2	A1	A2	FC
1	100,00%	27,27%	17,65%	100,00%	9,53%	23,08%	25,71%	100,00%
2	100,00%	27,78%	20,21%	20,83%	4,53%	100,00%	100,00%	84,45%
3	100,00%	18,67%	15,22%	11,20%	100,00%	100,00%	100,00%	100,00%
4	100,00%	24,14%	4,96%	100,00%	100,00%	100,00%	3,67%	100,00%
5	100,00%	10,83%	10,63%	100,00%	100,00%	100,00%	4,58%	57,43%
6	100,00%	9,17%	9,80%	9,01%	100,00%	100,00%	2,80%	47,62%
7	100,00%	15,79%	20,00%	17,91%	100,00%	100,00%	7,19%	100,00%
8	100,00%	100,00%	9,84%	11,11%	30,00%	25,00%	25,00%	100,00%
9	100,00%	100,00%	29,61%	26,09%	9,14%	7,86%	100,00%	100,00%
10	100,00%	75,00%	6,12%	6,32%	2,90%	2,97%	100,00%	100,00%
11	100,00%	15,91%	100,00%	6,20%	100,00%	100,00%	1,99%	100,00%
12	100,00%	100,00%	100,00%	100,00%	2,59%	3,12%	100,00%	100,00%
13	100,00%	27,78%	41,67%	100,00%	41,67%	100,00%	100,00%	100,00%
14	100,00%	26,53%	21,67%	12,75%	4,08%	4,96%	100,00%	100,00%
15	100,00%	75,00%	100,00%	16,67%	11,54%	6,12%	6,12%	100,00%
16	100,00%	75,00%	85,71%	5,94%	22,22%	17,14%	17,14%	20,69%
17	100,00%	83,33%	3,05%	3,07%	5,75%	4,27%	100,00%	3,97%
18	100,00%	85,71%	10,71%	10,35%	5,09%	5,61%	100,00%	1,67%
19	100,00%	75,00%	22,06%	10,49%	7,98%	7,04%	100,00%	100,00%
20	100,00%	75,00%	18,00%	15,52%	10,23%	12,68%	12,50%	100,00%

21	100,00%	73,33%	68,75%	18,97%	4,42%	4,20%	100,00%	1,41%
22	100,00%	70,37%	100,00%	100,00%	51,35%	32,76%	43,18%	6,76%
23	100,00%	74,07%	28,57%	30,30%	7,52%	100,00%	100,00%	3,79%
24	100,00%	83,33%	62,50%	26,32%	31,25%	5,68%	100,00%	100,00%
25	100,00%	83,33%	8,62%	100,00%	100,00%	100,00%	100,00%	19,48%
26	100,00%	86,67%	12,75%	11,50%	2,64%	100,00%	2,33%	2,16%
27	100,00%	100,00%	8,33%	100,00%	5,98%	5,88%	6,73%	1,58%
28	100,00%	100,00%	4,20%	100,00%	1,08%	100,00%	100,00%	100,00%
29	100,00%	75,00%	8,11%	100,00%	100,00%	100,00%	1,96%	5,11%
30	100,00%	80,00%	100,00%	100,00%	3,60%	100,00%	3,57%	2,42%
31	100,00%	81,25%	59,09%	31,71%	28,89%	100,00%	100,00%	2,42%
32	100,00%	81,82%	18,56%	100,00%	100,00%	100,00%	6,00%	4,02%
33	100,00%	78,57%	10,38%	100,00%	4,93%	100,00%	4,93%	3,68%
34	100,00%	75,00%	68,18%	26,32%	100,00%	100,00%	5,30%	4,84%
35	100,00%	83,33%	75,00%	5,79%	100,00%	100,00%	4,04%	100,00%
36	100,00%	77,27%	24,64%	22,37%	12,41%	100,00%	14,66%	10,18%
37	100,00%	80,00%	80,00%	20,00%	100,00%	100,00%	1,99%	100,00%
38	100,00%	85,71%	60,00%	27,27%	13,04%	11,32%	11,32%	31,58%
39	100,00%	70,83%	68,00%	50,00%	100,00%	100,00%	4,76%	12,41%
40	100,00%	85,00%	100,00%	16,35%	100,00%	100,00%	4,22%	100,00%
41	100,00%	78,95%	100,00%	24,59%	100,00%	5,49%	5,49%	100,00%
42	100,00%	100,00%	100,00%	9,38%	100,00%	5,95%	5,95%	100,00%
43	100,00%	77,78%	100,00%	41,18%	100,00%	2,08%	2,08%	100,00%
44	100,00%	100,00%	80,00%	7,21%	100,00%	3,19%	100,00%	9,70%
45	100,00%	71,43%	6,85%	6,33%	100,00%	1,02%	100,00%	100,00%
46	100,00%	4,85%	4,42%	3,49%	100,00%	1,56%	100,00%	10,81%
47	100,00%	80,00%	29,63%	29,09%	100,00%	4,76%	100,00%	5,52%
48	100,00%	60,00%	7,14%	7,89%	100,00%	2,01%	2,01%	100,00%
49	100,00%	85,71%	100,00%	54,55%	1,99%	2,01%	100,00%	100,00%
50	100,00%	61,90%	59,09%	16,05%	3,88%	4,00%	100,00%	100,00%
51	100,00%	64,29%	21,95%	25,00%	8,65%	6,29%	6,12%	100,00%
52	100,00%	71,43%	71,43%	71,43%	17,86%	17,86%	17,86%	100,00%
53	100,00%	4,08%	3,31%	3,05%	2,42%	2,47%	2,47%	100,00%
54	100,00%	83,33%	71,43%	41,67%	12,50%	11,63%	11,63%	5,10%
55	100,00%	3,82%	3,82%	3,60%	1,49%	1,62%	100,00%	100,00%
56	100,00%	66,67%	50,00%	20,00%	2,30%	1,78%	1,78%	100,00%
57	100,00%	9,76%	8,63%	6,82%	100,00%	100,00%	100,00%	21,82%
58	100,00%	11,01%	8,39%	6,78%	2,65%	100,00%	100,00%	100,00%
Av. OPSQ	100,00%	63,93%	42,05%	37,04%	46,35%	47,47%	47,88%	60,36%

- 3) If the production sequence is disturbed (the value of OPS for a defined block falls below the critical value), analyze the production flow cycle for this block (indicator PFC_{set_{av}}) at this PCP,

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- 4) Identify the type of disturbances based on the assessment of a production sequence and production flow indicator,
- 5) Choose suitable corrective actions and apply them at MRP level
- 6) Corrective action results in increase of indicator OPS over critical value see table point 2b for subsequent PCP