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FLEXIBLE PRODUCTION FLOW CONTROL SYSTEMS

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Abstract
Requirements regarding the quality and full traceability of delivered products in some industrial sectors, such as the food, pharmaceutical and automotive industries, where the life and health of the end user depends on the quality of the product, cause production flow control systems (PFC) to become an important element of the functioning of production enterprises. PFC systems are IT systems that are generally used for recording production data (in a database) at various stages of industrial processes, mainly from PLC controllers (in this respect they perform the function of traceability systems, that enable tracking products), but also provide blocking of identifiable products, which were incorrectly processed during earlier stages of production or follow wrong technology sequence. The desirable feature of such systems is their flexibility, which is characterised by their scalability and configurability. Configurability is the ability to include different processes into the PFC system in a relatively short time. The concept of a configurable system must be well considered and different material flow cases must be taken into account to avoid future dramatic changes in the IT system. Scalability is the ability to include more and more processes under control of the PFC system without the significant impact on its effectiveness. The PFC systems use computer networks to process production data, so the scalability of PFC systems depends on their modular architecture in the network. The article discusses basic features and possible PFC architectures, as well as two examples of configurable PFC systems along with their analysis and assessment. The described systems are the result of projects in which the author of this article participated, the aim of which was to develop and launch a flexible PFC system that meets the basic industrial requirements from the area of discrete manufacturing.

Keywords
production flow control, data registration, traceability.

1. Introduction

Requirements regarding the quality and full traceability of delivered products in some industrial sectors, such as the food, pharmaceutical, electronical and automotive industries, where the quality and life of the end user depends on the quality of the product, make the implementation of Production Flow Control systems (PFC) a very important element of business operations. For the food industry, traceability is not only required by regulatory agencies and third party audit standards, but it is a key element of risk management and control of food safety and quality. A robust, documented system that provides traceability, helping companies to meet regulatory or certification standards for food safety, supports to identify products quickly in the case of contamination [4]. The already existing traceability standards define product data identification, acquisition, as well as processing [3].

Traceability is a collection of complete and chronological information about unique identified products. It allows to distinguish materials when reporting and when analyzing the entire life cycle of a given product. This means that one can thoroughly analyze a unit product from the earliest stages of its production (the ability to identify materials from suppliers that were used to manufacture the product), through the production process (location of processes, stages, operators who participated in the production, service history, as well as information about possible failures or quality problems) to the final stage, i.e. sales and customer location. “Traceability” is not only a term used in the food industry. Also it is used in the electronics industry, where traceability is of great importance in the aspect of minimizing the costs of corrective actions. With the help of an unambiguous marking, one can track the origin of the final product along the entire supply chain, up to individual components. Unambiguous identification allows, in the case of a final product defect, to quickly isolate the source of the defect and launch a precise corrective action. In this way, the costs and financial losses associated with such actions can be significantly reduced. Traceability systems have become very important management information systems within the production companies as they can efficiently control the supply chain, by minimizing the risks of the production process, and helping to enhance the customer reliability on products [1]. Also according to [10] “traceability has become a critical risk management tool for a wide range of companies, including those in the food, medical, electronics and automotive industries”.

PFC systems are IT systems that are generally used to register production data at various stages of industrial processes (in this respect they perform the function of traceability systems, that enable tracking products), but also provide blocking of incorrectly processed identifiable products during earlier stages of production.

PFC systems ensure registration of information important from the customer's point of view (production date, numerical values of various parameters (e.g. angle, torque, pressure, temperature, length etc.), result of the operation (positive, negative)), which allow to detect defective products. PFC systems enable analyzing the reasons for these defects and defense against potential complaints or even a significant reduction in the number of complaints. Production Flow Control Systems bring manufacturing benefits to enterprises expressed through savings of capital allocated for managing complaints, but above all an increase in income through increased customer confidence and the opportunity to gain new markets.

A typical production system controlled by the PFC system consists of production stations managed by Programmable Logic Controllers (PLC) or PCs (in the industrial version with an external monitor) – Fig. 1.

The PFC system through a computer network and OPC server (commercially available software for communication with PLCs), or its own internal communication solution, reads information stored in the PLC about the result of the operation performed and the values of various types of important parameters (e.g. angles and angles of screwing operation, length, force etc.). These data are saved in a database (usually it is an SQL database) and are assigned to an unique identifier read from the product label in the form of a bar code, two-dimensional code or RFID data. When the product enters the next production station, the PFC system additionally queries the database, whether the previous operation was successful, whether the product follows the defined technological route and whether it is compatible with the currently implemented processing program set for the designated reference (product type, e.g. manual version, electric version, etc.) In the case of a negative response, the PFC system sends a PLC command to the production station through the OPC server. The PFC system can additionally support automatic setup of production stations, i.e. the reference read at the first production station in the technological process and assigned to the product is transferred internally to subsequent production stations with a change order (change of production station processing program).

One of the main challenges in traceability systems development is that there is no one solution that will solve traceability problems for every kind of industry. Traceability needs are dependent on the context of the organization and can differ from case to case in the same organization [9].

On the way to universality the desirable feature of PFC systems to match requirements of effective functioning and fast implementation is their flexibility, which is characterised by their scalability and configurability.

The described systems are the result of projects in which the author of this article participated, the aim of which was to develop and launch a flexible PFC system that meets the basic industrial requirements.

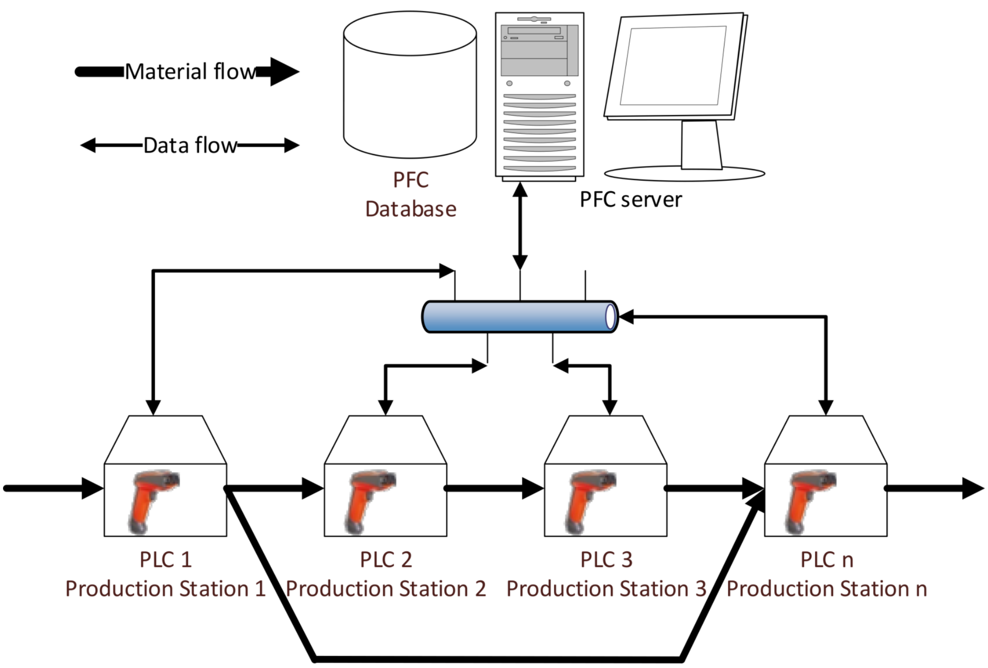


Fig. 1. Principle of PFC system operation with the case of two different material flows/routes [source: own development].

2. Configurable PFC systems

One of the aspect of flexibility of the PFC systems is the ability to be configured. Configurability is the ability to include different processes into PFC system in relatively short time. The concept of a configurable system must be well considered and different material flow cases must be taken into account to avoid future dramatic changes in the IT system. Configurable PFC systems allow the configuration of the number of production stations and their type (managed by PLC or PC), their network addresses, as well as the types of products allowed there, without changing the software itself. Figure 2 shows the view of the user interface of the PFC configurable system. The upper list allows vertical and horizontal scrolling of the list of production stations and checking if the communication works properly and in what mode the production station works ("Non-blocking" mode means that products made with a defect at the previous position during the route can be allowed to enter the current production station). Below the horizontal list there is a vertical list with lines, each of which indicates an event that occurred (product scan, end of technological operation). After selecting an event line, the product details with registered process values can be viewed in the fields below the vertical list.

The advantage of configurable solutions is the relatively short time of adding subsequent production stations, while the disadvantage can be (because of standard data structure) longer lasting queries to the database and longer exchange of information with PLCs. As an example, the system used in the automotive industry to control the assembly process of products can be cited. If a new production station is to be controlled by the PFC system, the user must first add the PLC to the list of controllers handled by the OPC server, giving it a unique identifier and network address.

Next the user has to take the following steps:

- define a new station with a unique designation in the xml configuration file (name, PLC identifier, data structure area in the PLC, etc.) – Fig. 3,
- within the production station in the same xml file specify what type-reference pairs are allowed,
- specify how the production station is located in the technological route (expected step number, next step number in the route, e.g. 0, 30 (0 means that the position is the first in the technological sequence)),
- specify which database function will be used to check the product status in the database (in this case the function has the name "MAIN").

```
<Station xsi:type="OPCStation">
  <Name>Stacja nr 1</Name>
      <OPC_Channel>0</OPC_Channel>
      <OPC_CPU>7</OPC_CPU>
      <DB_Number>120</DB_Number>
      <UnblockEnabled>true</UnblockEnabled>
      <RepairEnabled>false</RepairEnabled>
      <NumLabels>1</NumLabels>
      <NumValues>0</NumValues>
      <MaxReworks>0</MaxReworks>
      <ExtAttr></ExtAttr>
        <Rules>
              <BarCodeRule>
                    <RuleLabel>^8765432.*</RuleLabel>
                    <RuleReference>^9865432.*</RuleReference>
                    <FunctionName>MAIN</FunctionName>
                    <FunctionParam>0,30</FunctionParam>
              </BarCodeRule>
            <BarCodeRule>
                    <RuleLabel>^9543764.*</RuleLabel>
                    <RuleReference>^4387126.*</RuleReference>
                    <FunctionName>MAIN</FunctionName>
                    <FunctionParam>0,30</FunctionParam>
              </BarCodeRule>
            </Rules>
</Station>
```

Fig. 3. A part of the configuration file for a production station [source: own development].

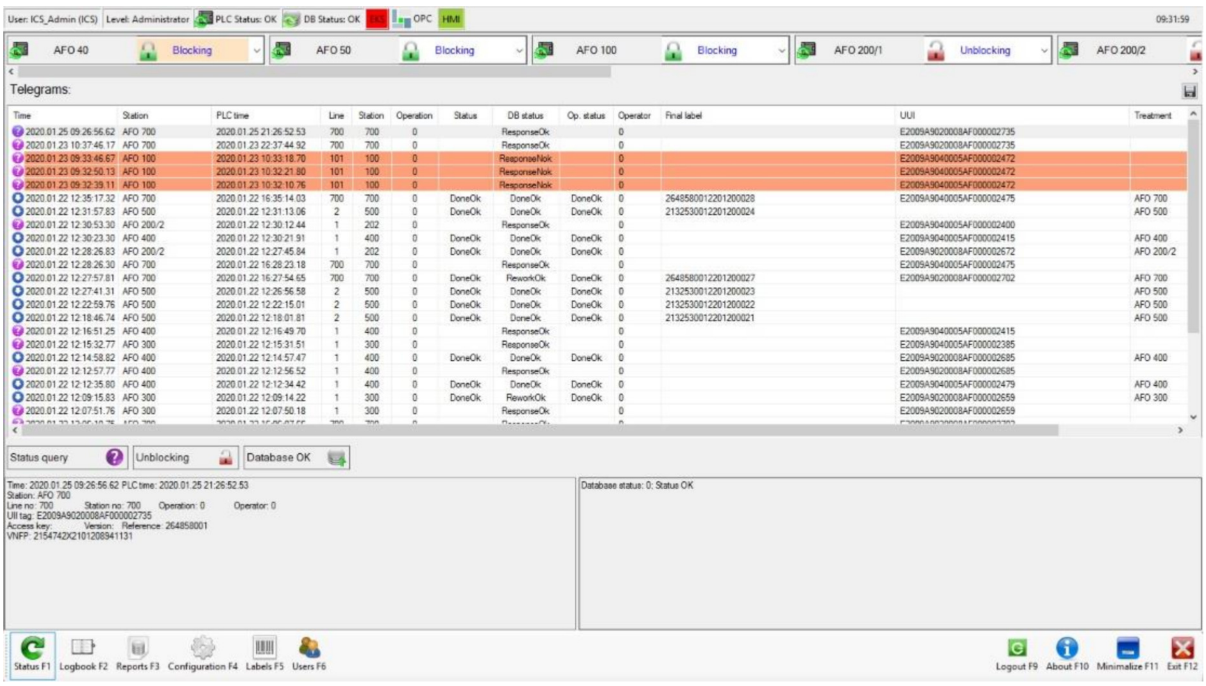


Fig. 2. View of the user interface of the sample PFC configurable system [source: own development].

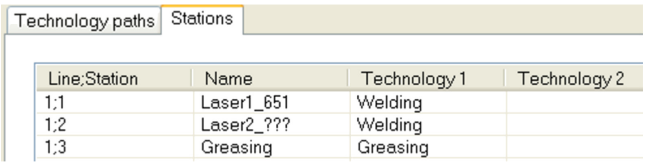
If a new version of the product (reference) is to be included, one shall complete the xml configuration file for the production stations through which the reference is to pass.

The discussed case gives the possibility of configuration with practically no restrictions. The disadvantage is that the technological route is defined in such a way that one has to number the next steps, which in the case of a large number of stations and a large number of references can lead to mistakes and confusion of the person configuring the system. An additional difficulty is the very need to use a configuration file, which can reach considerable sizes and thus can need more system effort to interpret it.

Another example of configuration is using a graphical user interface. In the case of adding a new version/type of the product (a reference) a technological route consisting of a sequence of technologies should be defined for the reference of the product.

In case of joining a new production station, which is to be controlled by the PFC system, the user must take the following steps (Fig. 4):

- define a new production station with a unique designation in the production stations' table,
- select the technology designation for the new production station (e.g. welding) – in the "Technology 1" column,
- define which technologies can be additionally implemented by the new workplace (in the "Technology 2" column).



Line;Station	Name	Technology 1	Technology 2
1;1	Laser1_651	Welding	
1;2	Laser2_???	Welding	
1;3	Greasing	Greasing	

Fig. 4. Window for definition of production stations [source: own development].

In case of adding a new reference of the product, a technological route consisting of a series of technologies should be defined for it (Fig. 5). The discussed case gives the possibility of configuration in a situation when the product reference is known and when it was determined which production station is first in the technological route. The first station behaves differently than the next ones, because it gives a reference for setup of subsequent production stations and adds a new row to the database. The subsequent production stations are subjects of the setup according to the reference code provided and after finishing the whole technology operation they complete the data in the database row of the product. Setting the functionality of the first production station requires a modification of the PLC algorithm. Another problem is the inclusion in the system of production stations where the reference is not yet known, e.g. welding stations, on which base products are produced to be developed into various references. Then they are outside the reference route and without using a special solution in the PLC it is impossible to check whether the order of these stations is correct.

Reference	Step 1	Step 2	Step 3
0000000	Greasing	RefChange	
1226324	Welding	Greasing	RefChange

Fig. 5. Window for definition of technology routes for references [source: own development].

3. Scalable PDC systems

Scalability is the ability to include more and more processes under control of the PFC system without the significant impact on its effectiveness. The PFC systems use computer networks to process production data, so the scalability of PFC systems depends on their modular architecture in the network.

Two kinds of PFC system architecture are to be considered: distributed and central server architecture. Distributed architecture is characterized by local traceability hardware and central database server, while central architecture is characterized by both central traceability and database server. In the following subchapters the both kinds of architecture are discussed. In the architectures the concept of the Station is understood as the production single unit (included into a Production Line) controlled by PLC or PC. The PLC or PC can control a larger number of Stations as well. The both architectures include groups of n Stations connected within local networks to separate them from the main network (to minimize the data flow) inside a group.

3.1. Distributed hardware architecture

Distributed hardware architecture is characterized by local traceability hardware and central database server. The components of the distributed hardware architecture are (Fig. 6):

- Traceability Point – a physical computer (can be Embedded PC mounted into existing infrastructure) with the OPC server and the traceability application to acquire data from the group of max. n Stations. It is a computer without a local database. It communicates with the central Traceability Database Server,
- Traceability Database Server – a powerful computer with database, which communicates with Traceability Points and provides data for reporting,
- Access Point – any physical computer with configured access to the Traceability Database Server and dedicated reporting application to generate production reports according to defined criteria.

The advantage of the architecture is the possibility to include more processes into traceability by adding new Traceability Points and configure them to be able to communicate with Database Server and Stations. The other advantage is, when one of Traceability Points fails (because of hardware problems), not the whole production system stops communicating (in this case local

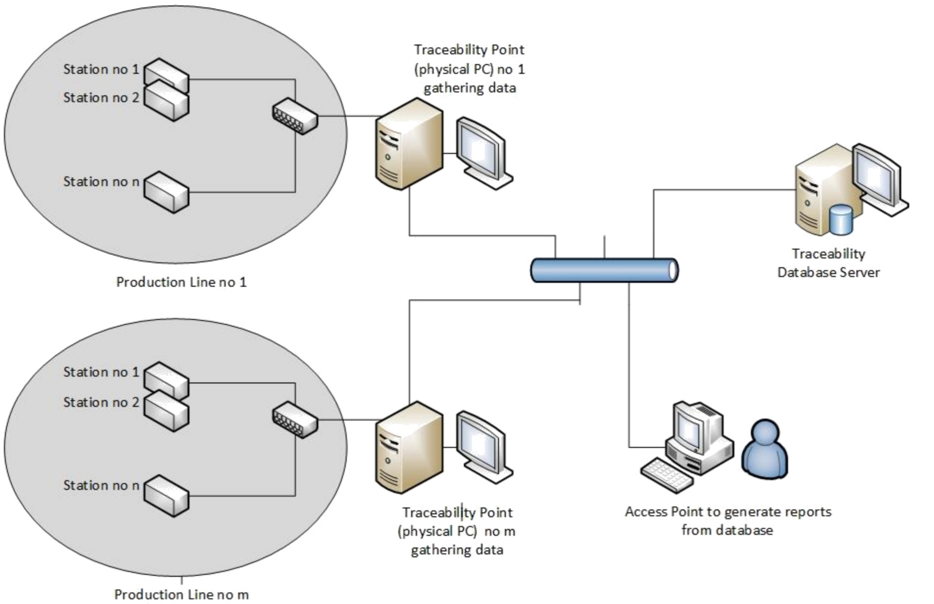


Fig. 6. Distributed hardware architecture of a PFC system [source: own development].

databases can be applied within Traceability Points). The other advantage is application of the database server, which is equipped with appropriate hardware and mechanisms to minimize risk of hardware fail and therefore higher database availability. The disadvantage can be necessity of maintenance of more Traceability Points (and therefore keeping some spare PCs to exchange the failed ones) and risk of hardware fail, which can cause stops in production until the problem is fixed.

3.2. Central server architecture

The central server architecture is characterized by both central traceability and database server. The components of the central server architecture are (Fig. 7):

- Traceability Server – a powerful computer server with the OPC server, database and Virtual Traceability Points running on it,
- Virtual Traceability Point – a virtual computer (not a physical PC, but using hardware resources of the Traceability Server) with traceability application to acquire data from the group of n Stations. It is a virtual computer without a local database. It communicates with the database which runs on Traceability Server,
- Access Point – any physical computer with configured access to the Traceability Server and dedicated reporting application to generate production reports according to defined criteria,
- Traceability Visualization – an optional physical PC to visualize traceability application for a production line and to use traceability functionality (i.e. printing spare labels, view data flow, querying a logbook to analyse causes of problems in the data flow etc.).

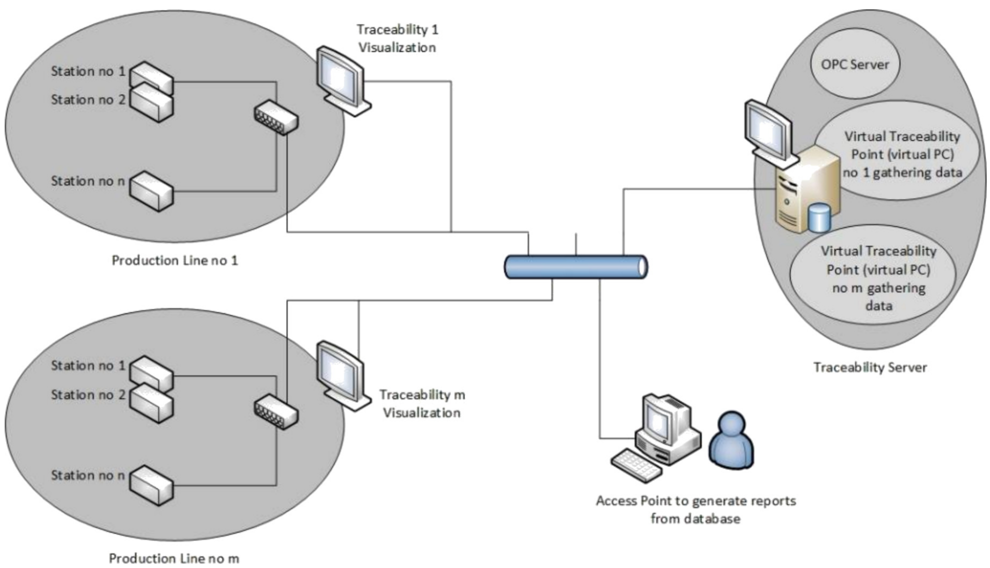


Fig. 7. Central server architecture of a PFC system.

The advantage of the architecture is possibility to include more processes into traceability by adding new Virtual Traceability Points and configure them to be able to communicate with the database and Stations. The other advantage can be maintenance of the whole traceability software in one place (e.g. there is no need to go to PCs and upload new version of traceability software), as well as having at disposal mechanisms of software backup using spare data discs and spare servers to avoid hardware problems. From the other side the disadvantage can be concentrating all of the traceability software on one server and therefore necessity to have more effective (expensive) hardware.

4. Systems on the market

According to the [6, 8, 10] latest reports, in case of traceability systems on the market mostly there is product marking based on barcode, QR code as well as RFID technology, which is applicable in the described PFC system. Furthermore, according to [10], "a framework is an essential part of any traceability system design as it enables a company to tailor a system to their specific products and requirements", which is directly connected with the scalability and configurability, therefore the flexibility issues.

One of the examples of traceability systems on the market is IQMS Manufacturing Trace system. According to [7] "the IQMS web-enabled suite of Track and Trace tools provides the visibility you need to quickly find, track and report critical information related to a product's location, production status, and supplier source". Its functionality includes among others: Regulatory and Compliance Reporting (production history reporting), Detailed Search and filtering (detailed database query), as well as Real-Time Production and Quality Monitoring (gathering events' data from devices), which corresponds to the functionality of the described PFC system.

5. Conclusions

Currently, manufacturers are struggling with increasing competition, and with growing customer requirements. Traceability systems support them in taking care about the quality of their products. Traceability systems are record keeping systems that show the path of a particular product from suppliers through intermediate steps to the consumers [5]. Manufacturers need proper information and data about the product location, its processing history, raw materials, etc. at each point so as to control the production process, therefore traceability has become one of the integrated parts of the supply chain logistics management [2]. The implementation of PFC systems is thus becoming a very important element of the functioning of companies, especially large organizations, or those operating in specialized market sectors that operate under high pressure of legal regulations. The ability to prepare, maintain and use the registered information minimizes the costs of withdrawing potentially harmful or unfit goods, as well as implementing preventive measures to eliminate production errors. A desirable feature of PFC systems is their configurability, which reduces the time to implement tracking of new production stations/products. The concept of a configurable system must, however, be well thought out from the very beginning and different cases of material flow configuration must be taken into account. A poorly thought-out concept in the case of new requirements/cases may result in the need for deep changes in the data structure and the application code itself. This may involve considerable unforeseen costs. Scalable PFC systems give the opportunity to include larger production systems without significant problems with effectiveness of communication and data processing. Having at disposal a scalable and configurable PFC system gives a technological advantage because it significantly reduces the time of adding a new production station to the PFC system as well as definition of a new technology sequence to recognise potential production failures.

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