A Production Control Support System Based on the Concept of an Artificial Pseudo Neural Network

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Abstract:

Purpose: The goal of the paper is to present the concept of a pseudo-neural network developed for production control in an industrial enterprise that produces complex products under discrete production conditions. This paper contains an attempt to use the theoretical basis of artificial neural networks to build a specialized tool. This tool is called a pseudo-network.
Design/Methodology/Approach: It is based not on the whole of the theory of artificial neural networks but only on the targeted elements selected for it. The selection criterion is the use of an artificial neural pseudo-network to control production
Findings: The concept of artificial pseudo neural network is fully presented in previous works by the authors.
Practical Implication: The network is part of the production planning and control system. In this system, the network acts as a subsystem responsible for production control. It cooperates with the production planning subsystem from which it periodically downloads the data on production task covering the assortment of manufactured products, production programs of individual assortment items, production start and end dates as well as its updates. In turn, it reports to the production planning subsystem about the progress of the implementation of the launched production task.
Originality Value: The presented approach is original and can be developed to meet requirements of various production systems. It has both cognitive and utilitarian potential.

Keywords: Artificial Intelligence, artificial neural networks, artificial pseudo neural networks, production control.

JEL classification: M2, L11.

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1. Introduction

Production control is the function of directing or regulating the flow of goods through the entire manufacturing cycle from the acquisition of raw material to the delivery of the finished products (APICS Dictionary, 1992). The important part of production control is dispatching – the selecting and sequencing of available jobs to be run at individual workstation. It was quickly noticed that artificial neural networks could be used to control processes (Willis *et al.,* 1995). The usefulness of artificial neural networks in production scheduling (Cheung, 1994) as well as tracking and adjustment of the production process were also found quickly (Guillot *et al.,* 1994). The network that was most often used to schedule production was the Hopfield network (Cheung, 1994). Moreover, one of the authors of this article worked on the idea of using the Hopfield network to schedule production (Fertsch, 2000; Fertsch, 2020; Kubiak and Stachowiak, 2013).

The experience gained during attempts to use artificial neural networks to production control has modified the general approach to this problem. A mixed approach appeared, based on combining artificial neural networks with other techniques of artificial intelligence (hybrid approach), (Sittisathanchai and Dagli, 1993; Lee and Dagli, 1997) or models of operational research (Fo and Takefuji, 1988). Artificial neural networks are information systems that imitate the operation of the human brain. Networks consist of several typical elements, such as, processing elements (neuron analogs), inputs and outputs, information, transfer functions, interconnections of processing elements, network learning principles.

This paper presents the results of an attempt to develop an information system designed and dedicated to the needs of production control in an industrial enterprise that produces complex products under discrete production conditions. The system consists of typical elements of artificial neural networks. Its structure, however, does not correspond to any of the typical artificial neural network architectures presented in the literature. Elements of the system and relations between them have been selected to enable the system performing production control function.

The authors called the developed solution the pseudo-neural network. The operation of the proposed pseudo-network in the general assumptions is based on the self-organizing map model. Cheung (1994) suggested the opportunity of using this model to solve production control problems. The self – organizing map includes the array of inputs with numerous connections to the processing layer. Every input element is connected to the processing layer through a localization function represented by the lateral connection weights. The developed information system consists of two layers of processing elements. The first one maps the production task, monitors the progress of its execution, and determines the order of performing all the activities the production task is composed of. The second layer assigns activities to the positions of the production system, tracks and analyses the state of the production system.

The solution of a localization function used in the developed pseudo-neural network is based on a certain assumption. It was derived from the analysis of the existing artificial intelligence tools. When considering the artificial intelligence tools, using the analogy

method seems to be the most common approach. Solutions are developed on the basis of available knowledge and understanding of the functioning of a specific system. An example of such an approach may be General Problem Solver by Nevell, Shaw and Simon (Rich, 1983) which imitates human thinking or expert systems that mimic the process of information analysis and decision-making (Jackson, 1998). Analogies have become the basis for developing neural networks, mimicking structures found in the brain (Haykin, 1994) or genetic algorithms based on mechanisms of natural selection (Mitchell, 1996; Fertsch *et al.,* 2017). Observation of natural environment is another source of inspiration for searching for new solutions.

Understanding the behaviour of numerous collections of individuals with limited intelligence, which becomes rational and intelligent from the point of view of the whole population, was an inspiration for tools such as models based on the behaviour of bee swarm, colony of ants or shoals (Bouffanais, 2016), as well as agent or multi-agent systems (Shoham and Leyton-Brown, 2008). The third source of inspiration in thinking about artificial intelligence tools seems to be abstract concepts in the field of mathematics, sociology or psychology, such as the concept of belonging to a set (group). They inspired tools based on fuzzy set theory or grey set theory.

The simplified analysis carried out above shows that among the tools of artificial intelligence there is a potential space for tools based on analogy to the behavior of numerous populations of intelligent individuals operating in a complex environment. The authors have attempted to build a pseudo-neural network based on the self-organizing architecture, in which a localization function is built on the analogy to the behavior of a set of drivers trying to cross a series of crowded intersections. They react to the current, dynamically changing state of the environment, events such as the impossibility of setting off on schedule or slowing down the traffic due to the traffic congestion. The result of this attempt is presented later in this article. The IT system based on the proposed architecture builds a schedule of produced elements that constitute a production task on an ongoing basis. It also has the feature of a smart system - the ability to create a virtual copy (digital twin) of physical reality and the ability to act autonomously until the situation requires no intervention from a higher level of management. Adding to this interoperability - the ability of machines, devices, products and services and people to communicate with each other - results in definition of the system capable of operating in architecture of cyber - physical systems for Industry 4.0 - based manufacturing systems.

2. Input Data – Entered to Layer 1

The Layer 1 maps the production task, monitors the progress of its execution, and determines the order of performing all the activities the production task is composed of.

2.1 The Matrix Describing Technological Processes

The matrix will contain descriptions of the technological processes of elements manufactured in the production system. The matrix is presented below in the form of a Table 1.

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Table 1. *The matrix describing technological processes*

Nr	Element ID	Operation number	$\sum t_j$	β
		Workstation ID		
		t_j operating time		

Source: Own study.

The elements in the table are ordered:
– by number of operations - from max to min
– if these are identical – by Σt_j value i.e., from max to min
– if the previous two criteria are identical – according to the value of the identifier – from max to min.

In the matrix of the description of technological processes there is also β - identifier of the possibility of starting a given operation, it takes either the value β = Y, when the operation is possible within the time limit or β = N in the opposite case.

The purpose of the matrix describing the technological processes of the elements produced in the production system is providing data for calculations carried out by the processing layer, which calculates (dynamically modifies) the localization function and the lateral connection weights.

2.2 The Matrix Describing Production Task Planned to Be Carried out in the Planning Horizon

It plays the role of array of inputs. The matrix will present a description of the production task planned to be carried out in the given planning horizon. In the lines there are individual elements planned for execution in the given planning horizon, in the columns individual planning orders (parts of elements). Elements in the matrix will be ordered in the order corresponding to the modified order in the matrix describing technological processes. The elements in Table 2 are ordered:

– by number of operations – from max to min
– if these are identical – by Σt_j value i.e., from max to min
– if the previous two criteria are identical – according to the size of the production program being the sum of the size of individual orders – from max to min.

The matrix is presented below in the form of a Table 2.

Table 2. *Matrix presenting a description of the production task planned to be carried out in the given planning horizon*

Nr	Element ID order number		P_p
		n_o	
		t_r	
		t_z	

Source: Own study.

The data in the matrix describing production task in the columns concerning individual production orders are taken from the MRP module of the ERP system:

– n_o – size of the production order,
– t_r – start date, the moment when task is launched,
– t_z – end date, the moment when task is finished.

The order numbers are assigned consecutively, according to the start date – from the earliest to the latest one. The size of the production program given in the last column of the matrix for a given element is the sum of individual sizes of the production task: $P_p = \Sigma n_o$.

3. Input Data – Entered to Layer 2

The second layer assigns activities to the workstations of the production system, tracks and analyses the state of the production system. The triangular matrix describing the structure of the production system plays the role of the processing layer in the network. The matrix will present the description of the structure of the production system (layout). It will contain separate locations in the production system. The following characteristics are assigned to each location:

– the workstation placed in this location
– distances from other separated locations.

The matrix is presented below in the form of Table 3.

Table 3. *The triangular matrix structures*

Nr	Location number	1
		Workstation ID
1	1	Distance from other locations

Source: *Own study.*

Locations in the table are ordered according to the distance from the dedicated location No. 1, which is the storage field at the production system, to which the elements to be machined go before and after machining.

4. Calculation of Localization Function and Lateral Connection Weights – Network Operation within Layer 2

4.1. For each structure of the matrix describing production system of k – location, distinguished in the matrix, excluding the location No. 1, calculate the initial potential using the formula 1.

$$c_{wk} = s \cdot h \tag{1}$$

where:
c_{wk} – initial potential of k – location,

s – number of working shifts in the planning horizon,
h – number of hours per one shift.

4.2. From the matrix describing production task for each j – element and each m – production order with the lowest number, calculate the "route" d_{jm} that it needs to go through in the production system:

$$d_{jm} = \sum_{i=1}^{j} d_i \qquad (2)$$

where:
i – number of operations performed on a given item/element,
d_i – distance between locations on which subsequent operations are carried out, if several locations are available for execution of i – operation, the nearest one should be selected.

4.3. Arrange the items and orders according to d_{jk} from the maximum to the minimum.

4.4. For the first of the element or order from the list, calculate the capacity demand for carrying i – operation cr_{ijm}

$$cr_{ijm} = n_{oi} \cdot t_{ji} \qquad (3)$$

where:
$cr_{ij}\,k$ – calculate the capacity demand for implementation of i – operation,
n_{oi} – size of the production order for i – operation,
t_{ji} – unit time of i – operation.

4.5. Assign i – operation on j – element or k – order to the nearest location at the earliest possible date.

4.6. For the selected location, calculate the current level of capacity of the given c_{bk} location:

$$c_{bk} = c_{wk} - cr_{ijm} \qquad (4)$$

4.7. Check whether it is possible to start i – operation on j – element or k – order due to availability of employees, material, tools ($\beta = Y$)? If so, arrange the resources necessary to perform this operation. If not, for the element or order being considered, calculate the number of operations:

$$l_{op} = l_b - 10 \qquad (5)$$

where:
l_{op} – number of operations on j- element,
l_b – current number of operations.
(Simulation of impossibility to leave at the scheduled time/ setting of delayed).

4.8. If the launching i – operation on j – element or k – order is possible on the scheduled date ($\beta = Y$), multiply the distance between the selected location and all other locations by α:

$$\alpha = \frac{c_{bk}}{c_{wk}} \tag{6}$$

(Simulation of slowing down the traffic due to traffic congestion).

5. Output of the System – An Example

To present example of the operation of the developed pseudo-network, data from industrial practice was used. The data concerned the production of small bodies manufactured from castings in a production unit operating in a machine building enterprise. The planning horizon covering 10 working shifts has been taken into account. The production plan was derived from the MRP module of the ERP class system used in the enterprise. The production plan, divided into production orders, is presented in Table 4. Table 5 contains a description of the manufacturing processes of the housings produced.

Table 4. *Production plan in the planned planning horizon*

Nr	Documentation ref.	Order number	1	2	3	4	5	6	7	8	P_p
1	334		40 1 5								40
2	101			20 1 6	10 5 10						30
3	041					10 3 7	12 4 10				22
4	346							10 4 10			10
5	724								75 4 11		75
6	040									40 6 9	40

Source: *Own study.*

Table 5. *Production processes: technology description*

Nr	Documentation reference	1	2	3	4	5	6	7	8	$\sum t_j$	β
1	334	FW 0.1175	V1 0.3735	SL 0.2952	ZH 0.0452	ZH 0.0452	SL 0.0187	PY 0.0723	ZH 0.0572	1.0248	Y
	101	FW	V1	SL	ZH	ZH	SL	PY	ZH		Y

2/3		0.0249	0.3159	0.0415	0.0104	0.0104	0.0416	0.0166	0.0131	0.4744	
4/5	041	V2	SL	FW	SL	PY	ZH			1.1152	Y
		0.0166	0.0623	0.0831	0.0623	0.0831	0.8078				
6,	346	V2	SL	FW	SL	PY	ZH			0.9759	Y
		0.5422	0.0542	0.0723	0.0542	0.0723	0.1807				
5	724	ZH	ZH							0,3796	Y
		0.1558	0.1600								
6	040	V2								0.2024	Y
		0.2024									

Source: Own study.

Two work schedules in the planned planning horizon were developed. The first one is shown in Figure 1 was developed with the capacity requirements planning in the "forward scheduling" version according to (Blackstone, 2008). This technique is used in CRP modules of ERP systems. For comparison, another schedule was developed with the proposed pseudo-network. It is presented in Figure 2.

Figure 1. CRP- forward scheduling
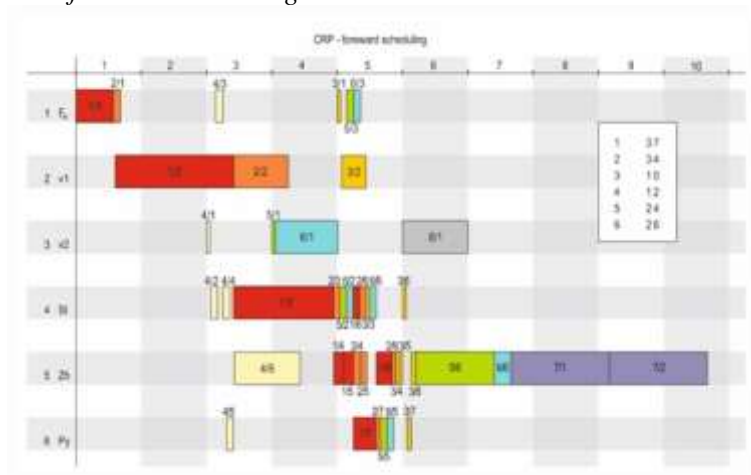
Source: Own study.

6. Conclusions

The limited comparative material prevents extensive generalization. Nevertheless, some conclusions can be introduced. The developed pseudo-network enables generating a schedule that can be compared with solutions obtained by other methods. Both solutions applied confirmed that the production plan is feasible in the planning horizon. The developed solution: pseudo – neural network for production control purposes will be the subject of further research.

Figure 2. *Schedule obtained with a developed method*
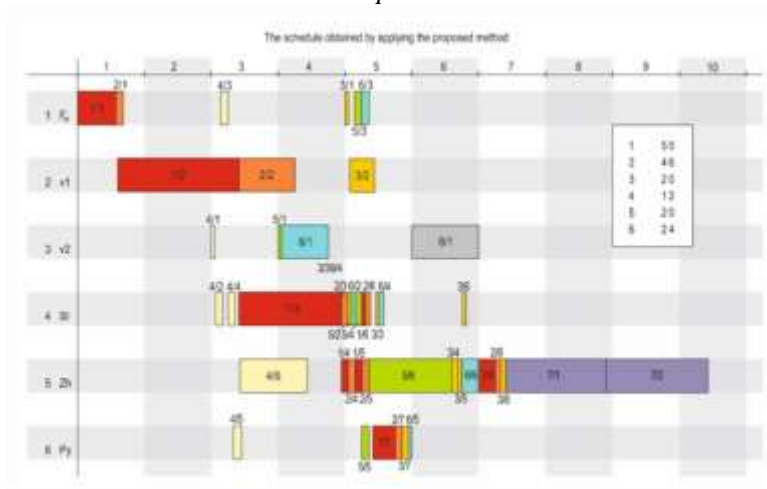
Source: Own study.

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