COMISSIONING PROCESS DESIGN OF PICK-TO-SEQUENCE MILK RUN IN THE CASE OF JUST-IN-SEQUENCE PRODUCTION

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Abstract: The improvement of supply chain systems leaded to the application of different inventory strategies. One of the most flexible inventory strategy is the just in time based just-in-sequence inventory strategy, especially in the case of flexible assembly lines. Flexible assembly lines are used in computer integrated manufacturing and assembly systems, where the up-to-date IT solutions supports the complex optimisation of just-in-sequence processes, where components arrive at the assembly line right in time as scheduled before they get assembled. The study deals with the optimisation of commissioning process in the on-site buffer in the case of just in sequence supply of assembly lines with milk runs. The author describes one possible model of this inventory strategy and shows the genetic algorithm based optimisation method of the commissioning sub process.

Keywords: commissioning, inventory management, just-in-sequence, logistics, on-site buffer

Introduction

Just-in-time and just-in-sequence concepts have been presented by the automotive and mechatronics industries in the past years [1.]. An important part of Toyota Production system is the just-in time concept, which eliminates, as much as possible, waste resulting from waiting, stock reserves, and defective parts [2., 3.]. Just-in-sequence supply tops just-in-time by adding the right sequence for supplied parts and components. Just-in-time and just-in-sequence require high discipline of both, supplier and manufacturer [4., 5.], therefore it is very important to design and optimise the processes of these inventory strategies. Just-in sequence supply requires an inventory of parts that can be picked in the right sequence [6., 7.]. The three basic parts of just-in-sequence conception are the integrated data processing through the whole supply chain (suppliers, manufacturers, and customers), production or assembly segmentation, production or assembly synchronous material supply [8., 9.].
There are three different types of just-in-sequence inventory management. In the case of *pick-to sequence* strategy (PS), components are picked from production-internal storages, order and transported by the aid of milk runs to the flexible assembly line. The advantages of this strategy are the followings: storage spaces are reduced near to assembly lines; WIP and cycle time can be increased. In the case of *ship-and-receive-to-sequence* strategy (SRS) components are ordered at the supplier and transported directly to the assembly line. The advantages of this inventory strategy are the followings: storage spaces and amount of stored components are reduced; reduced material handling costs. In the case of *make-assemble-build-to-sequence* strategy (MABS) components are produced and ordered in the plant of the customer. This inventory strategy has the same advantages as the SRS strategy has.

Modelling of pick-to-sequence component supply

From the above mentioned three types of just-in-sequence inventory strategy the most transparent is the pick-to-sequence strategy, where the required sequences of flexible assembly lines are built in the different on-site buffers of the assembly plant. Figure 1. shows one possible model of this pick-to-sequence component supply problem. The complexity growth influence the efficiency, functionality and transparency of large assembly systems based on a huge number of final products and therefore it is important to research the effects of sub-processes of this just-in-sequence supply.
The main elements of the model of just-in sequence supply of flexible assembly lines with milk run are the followings:

- one or more on-site buffer: components are transported in arbitrary way from the supplier to the on-site buffers and the components are picked from these on-site buffers;
- milk-run: delivery method (and transportation device) for mixed components from one or more on-site buffers to the flexible assembly lines;
- flexible assembly lines: component requirement will be fulfilled by milk runs based on just-in-sequence philosophy.

During the design process of the pick-to-sequence system the following optimisation problems have to be solved:

(a) Optimisation of the number and location of on-site buffers.
(b) Optimisation of the number of milk runs and route planning of each milk run.
(c) Optimisation of relationship of on-site buffers and milk runs.
(d) Optimisation of storage location of each component in each on-site buffer.
(e) Optimisation of commissioning process of components in on-site buffers.
(f) Distribution and scheduling of milk runs among the flexible assembly lines.

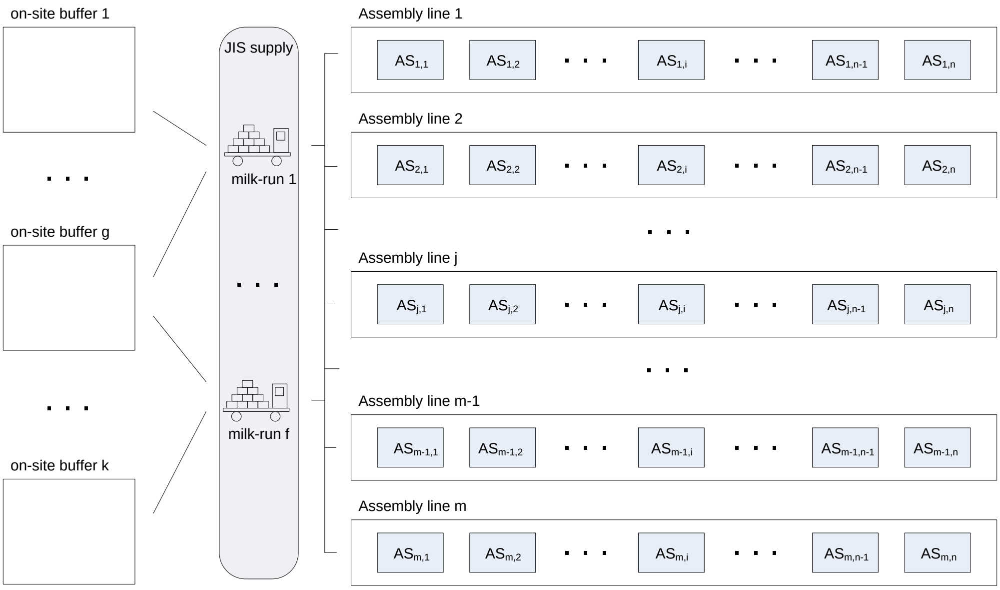

Figure 1: Model of just-in-sequence supply of flexible assembly lines with milk runs

Within the frame of this research work the commissioning process optimisation was chosen. There are several research works dealing with process optimisation in warehouses and buffers [10., 11., 12., 13.]. From the point of view of computational complexity, these process optimisation problems are non-deterministic polynomial-time hard (NP-hard), depending on the complexity of objective functions and constraints.

Mathematical modelling

During the optimisation of the above mentioned commissioning problem (see figure 1.) the following assumptions have to be taken into consideration:

(a) The sequence of component demand of each assembly station of flexible assembly lines is given.
(b) The component demand of each assembly station is fulfilled within the frame of a given cycle time. The cycle time is given.
(c) The milk runs are ordered to the assembly stations and assembly lines.
(d) The storage place location in each on-site buffer is given.
(e) The capacity of milk runs is high enough to transport the scheduled component demand within the frame of one route.
(f) Depending on the chosen strategy one milk run can be able to pick components from more on-site buffers and one on-site buffer can offer components for more milk runs.

There are a high number of the mathematical models depending on the complexity of the problem. The general input parameters of the mathematical model are shown in the table 1.

Table 1. Input parameters

Input parameter	Explanation for the input parameters
$D^b = \left[d_q^b\right]$	Vector of sequenced demands delivered to the assembly stations of flexible assembly lines by the b^{th} milk run and $-\ d_q^b$ is the q^{th} demand delivered to the assembly station of flexible assembly lines by the b^{th} milk run.
$S^r = \left[s_{k,l}^r\right]$	Layout matrix (ordered set of storage positions) of components stored in the r^{th} on-site buffer and $-\ s_{k,l}^r$ is the component type stored in the (k,l) position of the r^{th} on-site buffer.
$P^b = \left[p_{\alpha,\beta}^b\right]$	Matrix of the possible pick position of components to be delivered by the b^{th} milk run to the assembly stations of flexible assembly lines and $-\ p_{\alpha,\beta}^b$ is the β^{th} possible pick position of component α.
$R^\theta = \left[r_{\vartheta,\rho}^\theta\right]$	Route matrix of the possible pick positions among different on-site buffers inside of on-site buffers in the case of the θ^{th} milk run and $-\ r_{\vartheta,\rho}^\theta$ is the length of the route between ν^{th} and ρ^{th} pick position in the case of the θ^{th} milk run. Figure 2. demonstrates the matrix structure in the case of a simple pick-to-sequence process.
f	Number of milk runs.
w	Number of pick positions.
c^b	Specific cost (time, length of route, energy consumption).

The objective function of the commissioning process optimisation problem is the minimization of the commissioning routes among picking position depending on the sequenced demands of assembly stations and four constraints have to be taken into consideration (see table 2.)

$$C = \sum_{b=1}^{f} \sum_{i=1}^{w} R^{b}_{x_{i+1},x_i} \cdot c^b \rightarrow min.$$

Within the frame of the optimisation different measures can be used to calculate, depending on the measure of specific parameter: sequencing time, cost of sequencing, length of route required for sequencing, energy consumption of sequencing (commissioning). The decision variable of the optimisation problem is the X vector, which represents the route of each milk run in the on-site buffers.

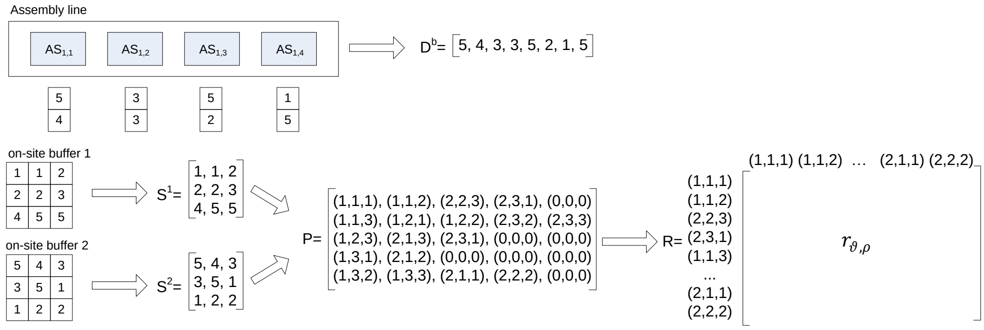

Figure 2: Example for the matrix structure in the case of one assembly line, one milk run, two on-site buffers and five different components (the number of components required within the frame of the cycle time is eight)

Table 2. Constraints I.

Constraints	Explanation for the constraints
$\forall d_q^b \in \Upsilon^b$	Each component required by the assembly stations of flexible assembly lines must be sequenced, picked and delivered by milk runs and Υ^b is the set of components picked by the b[th] milk run.
$\forall d_q^b \in \Omega$	Each required component must be available in the on-site buffers and Ω is the set of components available in the on-site buffers.
$\sum_{b=1}^{f} \sum_{i=1}^{w-1} R^{b}_{x_{i+1},x_i} \cdot v^b \leq \tau$	The cycle time of the flexible assembly lines must be higher than the total commissioning time (which can be calculated as the sum of sequencing and picking time) and v^b is the velocity of the b[th] milk run and τ is the cycle time of the flexible assembly line assigned to the b[th] milkrun.
$z^b \geq s^b$	The capacity of each milk run must be higher than the total demand to be delivered within the frame of the cycle time and z^b is the capacity of the b[th] milk run, s^b is the number of components to sequenced, and delivered by the b[th] milk run.

Heuristic optimisation method

Because of the high number of components and assembly stations of flexible assembly lines from the point of view of computational complexity, these process optimisation problem is a non-deterministic polynomial-time hard (NP-hard) problem. These NP hard problems can be solved with metaheuristic. Metaheuristic is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [14.]. The application of different metaheuristic methods is a well known way to solve NP-hard problems: for example pattern search [15.], evolutionary programming [16.], tabu search [17.], glowworm swarm optimisation [18.], harmony search [19.] and galaxy based search algorithm [20.] can be used to find good solutions for NP-hard problems. As a possible solution the genetic algorithm was chosen, which is a heuristic optimization method using techniques based on mechanisms from biological evolution such as mutation, crossover, and natural selection to find an optimal configuration for a specific environment according to specific conditions.
Figure 3. shows the representation of one possible commissioning process of one milk run. The phenotype consists of the co-ordinates of components to be sequenced, picked and delivered to the assembly stations of flexible assembly lines. The first step of the GA process is the random definition of initial population. However the phenotypes of the initial population can be generated randomly, but one constraint has to be taken into consideration (see table 3.).

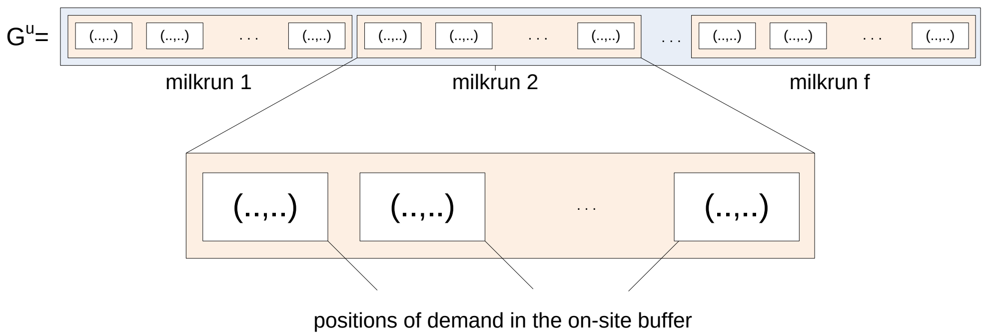

Figure 3: Structure of a phenotype, which encodes a candidate solution of the commissioning problem (solutions are represented usually in binary, but this encoding with co-ordinates is also possible)

Table 3. Constraints II.

Constraints	**Explanation for the constraints**	
$G = [g_j]$ *and* $\forall g_j \neq \forall g_i$ *and* $i \neq j$	It is not allowed to pick two different components from the same co-ordinate of the on-site buffers. This constraint has to be taken into consideration in the following phases of the GA: initialisation of the first population, crossover and mutation operators. G is a hypervector including	
	g_j	vectors related to the pick positions of each milk run.

The next step of the GA is to use the three basic operators: selection, crossover and mutation. During selection, a predefined proportion of the existing population is selected based on their fitness. Crossover creates new individuals (phenotypes) by combining parts of two or more individuals. However in this optimisation problem the PMX, OX or CX operators can be used but is was more simple to create a new crossover operator dedicated to this problem. If we choose the classical one-point crossover operator, then a single crossover point on both parents' phenotype is selected and all positions of components beyond that point in either phenotype is swapped between the two parents.

$$g_{x,\gamma}^{n+1} = \begin{bmatrix} g_{x,\gamma}^{n} \ if \ \gamma \leq p \\ g_{y,\gamma}^{n} \ if \ \gamma > p \end{bmatrix} \qquad g_{y,\gamma}^{n+1} = \begin{bmatrix} g_{y,\gamma}^{n} \ if \ \gamma \leq p \\ g_{x,\gamma}^{n} \ if \ \gamma > p \end{bmatrix}$$

If the phenotype consists of the same co-ordinate of the on-site buffer, then one of them must be changed.

The last operator is the mutation operator. The purpose of this operator is preserving and introducing diversity. The application of mutation operator is important to avoid local minima.

$$g_{x,p}^{n+1} = P(p, \varepsilon)$$

where p is a random number and ε is the upper limit of possible co-ordinates of the p^{th} component in the on-site buffers. P is the matrix of possible pick positions.
After using these three operators we can calculate the fitness of each phenotype and analyse the termination condition (see figure 4.).

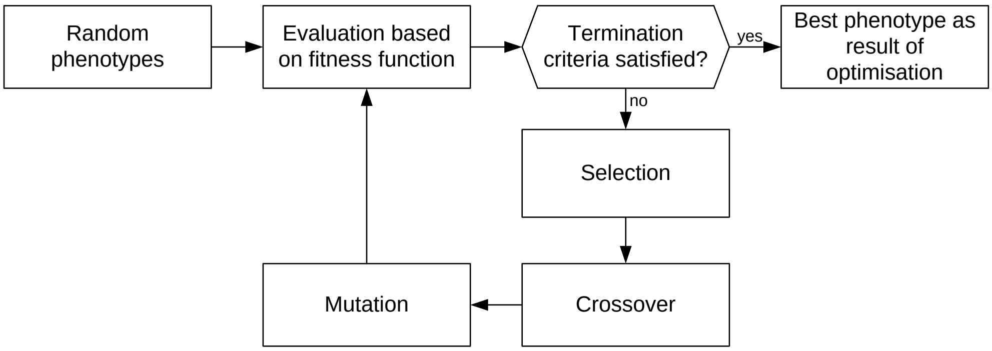

Figure 4: Structure of a simple genetic algorithm

Using the above mentioned mathematical model of commissioning process in the on-site buffer in the case of just-in-sequence supply of assembly lines with milk runs it is possible to optimise the commissioning process from the point of view of time, cost or energy consumption.

Consequences

The globalisation and the increased market demand leaded to the requirement to optimise all processes of production and manufacturing. New philosophies were founded and applied in the field of purchasing, production, distribution and inverse logistics. One of these philosophies is the just-in-time based just-in-sequence inventory management. Within the frame of this paper the author focuses on the pick-to-sequence inventory strategy and developed a model to describe the process of just-in-sequence supply of assembly stations of flexible assembly lines based on milk runs. The author described the commissioning process and worked out a genetic algorithm based metaheuristic to optimise the sequencing route of each milk run.

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