IMPACT OF A JUST-IN-SEQUENCE SYSTEM ON THE EFFECTIVENESS OF INTERNAL TRANSPORT IN AUTOMOTIVE INDUSTRY

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Abstract

Just-in-Time (JiT) system, used by most manufacturing companies, is being increasingly replaced by more efficient Just-in-Sequence (JiT) system. The latter one allows direct delivery of products to the production line without the warehouse storage process. In this paper the impact of JiS application on the effectiveness of internal transport system in a manufacturing company (automotive industry) is examined. Two mathematical models (for JiT and JiS) have been developed to map the manner and duration of the processes of components’ transportation to the production line. For both systems the effectiveness analysis was made to determine the benefits of using the Just-in-Sequence system: the economy of time, manpower, means of transport and storage space.

Keywords:
Just-in-Time, Just-in-Sequence, internal transport, automotive industry, effectiveness

1. INTRODUCTION

In Poland, there are more than 660 manufacturers of automotive parts and 350 of them hold top-quality certificates such as ISO/TS 16949. They manufacture parts for all automobile makes. As many as 9 out of 10 leading world manufacturers of parts have their manufacturing plants in Poland. Major operators in the Polish market include Bosch, Brembo, Delphi, Gates, Johnson Controls, Mahle, Tenneco Automotive, ThyssenKrupp Automotive, TRW Automotive, and Valeo. According to a report by the Polish Association of Automotive Parts Distributors and Manufacturers (SDCM), 20% of the parts used for assembling automobiles come directly from automotive companies whilst 80% of them are supplied by independent manufacturers who sell products under their own brands [1]. The system for the distribution of finished products depends on the requirements set by end-customers. Due to the specificity and continuity of operation of manufacturing lines, the manufacturing industry and the automotive industry in particular, set the highest requirements for their suppliers. These apply not only to the high quality of sub-assemblies but the organisation of supplies themselves and delivery of products within specific time windows. For the purposes of delivery processing, manufacturers of automotive parts divide their customers into specific groups, for instance [2–5]:

- OEMs (Original Equipment Manufacturers);
- OESs (Original Equipment Services); and
- AAMs (Automotive Aftermarket).
The division of customers into groups is very important due to the timeliness of deliveries and the consequences of the failure to meet their terms and conditions. Parts delivered to OEM customers are the ones to get into serial production. In order to optimise operations, most manufacturers reduce their inventories to zero thus eliminating the loss of capital frozen in the stock. The parts delivered to them get straight into production following the JiT (Just in Time) and JiS (Just in Sequence) rules. Because of that, non-delivery of a part on time may cause stoppage of the manufacturing line thus exposing the supplier to huge costs. Hence, customer logistic services provided to OEMs require high precision and long-term production planning. The parts for such customers are manufactured as first priority. The delivery schedules are provided one year in advance in order to plan the Master Production Schedule. The nature of the OEM customer group requires that methods are set to ensure timely deliveries, which is discussed further in the paper. What is most important to this group of customers is the timeliness and flexibility of deliveries. The volume of each order, apart from the order freezing period, may change within a certain percentage range. The customer requires the option of having the product delivered in bigger or smaller quantities. Flexibility is also understood as the possibility of moving the time of delivery backward or forward, as required by the customer. The OEM customer group requires continued contact to be kept and information to be provided about any problems or complications.

The second group is OES customers for whom parts are delivered to authorised service points of automotive manufacturers. OES parts as the same as the ones for the OEMs but with different reference names in order to follow the safety requirements and distinguish between production priorities. For most projects, OEM and OES parts are shipped at the same time but to different destinations. After the termination of the contract for supplies for the assembly line, the manufacturer of subassemblies is obliged to continue production for a certain period of time or keep a certain stock level with the OES customer. The primary characteristic with respect to this customer group is the capability of processing orders which change frequently following changeable demand. Timeliness of deliveries is a secondary issue. For many customers, the acceptable time of delivery is within the tolerance range of two days from the required delivery date. This also relates to optimisation of the loading space in means of transport. The other aspect is the completeness of deliveries – the customer requires delivery of all ordered parts. A long shortage of a particular range of products may prevent the customer from providing due service or considerably delay the same.

The third group are AAM customers who offer distribution of spare parts in the market to individual customers. For this group, timeliness is the most important factor in logistic services.

The article presents a comparative analysis of Just in Time and Just in Sequence systems of components delivery, depending on the type of parts, as direct delivery combined with JiT system. Direct delivery to the assembly line, i.e. with no storage in the main warehouse (JiS) is also considered. To evaluate the effectiveness of JiT and JiS systems a comparative analysis of variants is employed.

2. PRODUCTION PROCESS

Assembly lines are process-oriented and are arranged according to the sequence of operations needed to manufacture a product. This is in contrast to job shops which are job-oriented and machines which perform similar operations are spatially grouped together [6].

Automobile manufacture cycle can be divided into stages within which a series of jobs is performed in a sequence. An assembly line with tasks assigned to each workstation significantly accelerates the manufacture, reduces the risk of errors and reduces the skills requirements
of workers who need to be skilled only in the tasks required for a particular workstation [7]. The car production cycle can be divided into the following stages:

1. Preparation of car body
2. Disassembly of doors
3. Fitting doors with glass, locks, door panels, etc. (performed at a separate workstation)
4. Assembly of groups of electric wires
5. Assembly of floor carpeting, roof lining, seat belts
6. Assembly of gear box wrapping connector
7. Assembly of windows, front and tail lights, and indicator lights
8. Assembly of pillars covers, trunk carpeting
9. Assembly of interior area with dashboard and pedals
9B. Subassembly of interior area module (manufactured at a separate stand)
10. Assembly of engine and exhaust system
10B. Subassembly of the module of engine and exhaust system (manufactured as a separate stand)
11. Assembly of suspension system
11B. Subassembly of suspension system (manufactured at a separate stand)
12. Assembly of bumpers
13. Connecting wire groups to power source
14. Assembly of wheels
15. Assembly of seats
16. Assembly of steering wheel and air bag
17. Fuelling and filling with operating fluids
18. Firmware installation
19. Verification of vehicle parameters
20. Assembly of doors
21. Wheel geometry setting and lights adjustment
22. Inspection of braking system
23. Inspection of tightness

To ensure the continuity of production it is essential to ensure the delivery of required parts to each workstation. Any delay in parts timely supply may cause stoppage at a workstation, which results in the stoppage of the entire production line. This makes it absolutely fundamental to eliminate any delays [8]. Moreover, automotive manufacturing companies aim at limiting their inventory level to reduce the storage space and the capital frozen in the stock. Therefore, what is most important is that orders be delivered more frequently, with no need of keeping the parts in storage over long periods. Parts are delivered to manufacturing plants in Just-in-Time and Just-in-Sequence systems [9].

3. COMPARATIVE ANALYSIS OF JIT AND JIS SYSTEMS

The system of internal transport in manufacturing plants with an assembly line is of particular significance because an error in this area may result in the stoppage of production line. Therefore continuous control of supplying the workstations is required. For each workstation the principle of inventory reduction is followed, at a workstation there should be only the parts that are necessary to perform the assembly jobs in one cycle, at the end of which the workstation should be supplied with components necessary for the subsequent cycle. Consequently, it is necessary to maintain an order and cleanliness of a workplace as well as continuous control of the production process. To achieve this aim the principle of 5S and Kanban card are employed [10].
Components can be delivered to assembly stations as direct delivery or in-time systems performed by logistic trains.

In direct delivery system only one workplace is supplied by a single event of collecting parts from the warehouse and transporting them. This system is most common in the case of large components, no production synchronization between a given workplace and other stations or emergency cases (e.g. lack of parts at the workplace due to incorrect previous delivery, defects of parts etc.).

In-time systems performed by logistic trains are much more efficient. They help reduce the total distance of parts transportation, the number of transportation means moving within a manufacturing plant. All this results in cost reduction by reducing the workforce, transportation means and services. The logistic train is a truck composed of modules that can be uncoupled. The modules are made up of containers loaded with parts and as the truck moves on, they are dropped at the workplaces while the empty containers are picked up to be reloaded. An example of a logistic train is shown in Figure 1.

![Logistic train](image)

**Figure 1** – Logistic train transporting parts to assembly workstations

In the article components delivery systems performed depending on the type of parts in direct delivery systems combined with in-time systems (JiT) are discussed. Delivery directly to the assembly line, i.e. with no storage in the main warehouse (JiS system) is also analysed. To evaluate the efficiency and effectiveness of JiT and JiS systems a comparative analysis of two variants has been made.

### 3.1. Variant I – JiT

In variant I only the employment of JiT delivery to a company is considered. All the components are stored in one warehouse. They are distributed to particular workplaces by direct and in-time deliveries. The warehouse must have a considerable storage space and a stock of parts. A scheme of the production line is shown in Figure 2.
Figure 2 – Production line with JiT components delivery; numbers of processes as in subsection 2

For the arrangement of the production line shown above the workplaces were divided according to the demand for direct or in-time deliveries.

For supplies which are realized in JiT system, the mathematical model was developed. This model enables to determine time of parts supplies to all assembly station during one full production cycle. This model is described by formula (1).

\[
T_{i} = \sum_{n=1}^{m} \left( \sum_{j=1}^{i} (d(i-1,i) \cdot v_m + t_{m}(i)) + d(i,s) \right)
\]

(1)

where:

- \(T_{i}\) – the time of supplies all parts in one full production cycle, s,
- \(n\) – the logistic train,
- \(m\) – the number of all logistic train supplying the parts,
- \(d(i-1,i)\) – the distance between previous and actual station, m,
- \(d(i,s)\) – the distance between last station and warehouse, m,
- \(v_m\) – the average speed of logistic train in one meter straight line, m/s,
- \(i\) – the assembly station supplied by logistic train,
- \(j\) – the number of assembly stations,
- \(t_{m}(i)\) – the time of operational activities at \(i\)-assembly station, s.

In analyzed example in both models the time of loading parts into logistic train bins or forklifts (for direct supplies in buffer warehouses in JiS system) is the same. Because of that and that the aim of simulation was to compare effectiveness of both systems (variant I and variant II) the mentioned times of loading were omitted in both developed models.
Based on the above mathematical model simulations were performed, the results of which are presented in the table 1.

This division together with delivery time of all the components required for a given workplace is shown in Table 1.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Jobs</th>
<th>Direct delivery</th>
<th>Logistic train</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preparation of car body</td>
<td>79</td>
<td>x</td>
<td>79</td>
</tr>
<tr>
<td>2</td>
<td>Disassembly of doors</td>
<td>13</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Fitting doors with windows, locks, door panels, etc. (separate workstation)</td>
<td>x</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Assembly of groups of electric wires</td>
<td>x</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>Assembly of floor carpeting, roof lining, seat belts</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Assembly of gearbox wrapping connector</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Assembly of windows, front and tail lights and direction indicator lamps</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>Assembly of pillars covers, trunk carpeting</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>Assembly of interior area with dashboard and pedals (as a ready-made element)</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>9B</td>
<td>Subassembly of interior module</td>
<td>x</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>10</td>
<td>Assembly of engine and exhaust system (as ready-made element)</td>
<td>13</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>10B</td>
<td>Subassembly of engine and exhaust system module</td>
<td>x</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>Assembly of suspension (as ready-made element)</td>
<td>13</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>11B</td>
<td>Subassembly of suspension module</td>
<td>x</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>12</td>
<td>Assembly of bumpers</td>
<td>x</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>14</td>
<td>Assembly of wheels</td>
<td>x</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>Assembly of seats</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>16</td>
<td>Assembly of steering wheel with air bag</td>
<td>x</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>17</td>
<td>Fuelling and filling with operating fluids</td>
<td>x</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>Assembly of doors</td>
<td>21</td>
<td>x</td>
<td>21</td>
</tr>
<tr>
<td>TOTAL</td>
<td>[s]</td>
<td>139</td>
<td>368</td>
<td>507</td>
</tr>
</tbody>
</table>

The table does not include components loading/unloading time because this time is the same in both variants and does not affect the result of the comparative analysis. In the “Logistic train” column the two delivery types are marked with different colours.

### 3.2. Variant II – JiT and JiS

In variant II the possibility of combining two systems of components delivery, i.e. JiT and JiS is analysed. In this variant it is necessary to use buffer warehouses for the storage of components specified for a given workplace. The parts from the buffers are delivered directly to the assembly line, which enables the reduction of transportation distance and the volume of stock. The main warehouse is used for the storage of parts of relatively low value and high demand.
on the production line. Such parts include, for instance, screws, pads, gaskets and seals, operating fluids. They are delivered as in variant I, i.e. in direct and in-time delivery systems. A scheme of a production line with indicated buffer warehouses is shown in Figure 3.

For the system above – like in variant I – the workplaces are divided according to the demand for direct or in-time deliveries.

For supplies which are realized in JiT mixed with JiS system, the mathematical model was developed. This model enables to determine time of parts supplies to all assembly station during one full production cycle. This model is described by formula (2).

\[
T_i = \sum_{m=1}^{m} \left( \sum_{i=1}^{(d(i-1, i) \cdot v_m + t_m(i))} + d(j, s) + \sum_{k=1}^{j} (2d(k) \cdot v_m + t_m(k)) \right)
\]

where:
- \(T_i\) – the time of supplies all parts in one full production cycle, s,
- \(n\) – the logistic train/forklift,
- \(m\) – the number of all logistic train/forklifts supplying the parts,
- \(d(i-1, i)\) – the distance between previous and actual station, m,
- \(d(j, s)\) – the distance between last station and warehouse, m,
- \(v_m\) – the average speed of logistic train in one meter straight line, m/s,
- \(I\) – the assembly station supplied by logistic train in JiT system,
- \(j\) – the number of assembly stations in JiT system,
- \(k\) – the assembly station supplied by forklifts in JiS system,
Based on the above mathematical model simulations were performed, the results of which are presented in the table 2.

This division together with delivery time of all the components required for a given workplace is shown in Table 2.

**Table 2** – Type of components delivery for a given stage and delivery time for variant II [s]

<table>
<thead>
<tr>
<th>Stage</th>
<th>Jobs</th>
<th>Direct delivery</th>
<th>Logistic train</th>
<th>Delivery from warehouse buffer</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preparation of car body</td>
<td>x</td>
<td>x</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Disassembly of doors</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Fitting doors with windows, locks, door panels, etc. (separate workstation)</td>
<td>x</td>
<td>40</td>
<td>x</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>Assembly of groups of electric wires</td>
<td>x</td>
<td>28</td>
<td>x</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>Assembly of floor carpeting, roof lining, seat belts</td>
<td>x</td>
<td>6</td>
<td>x</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Assembly of gearbox wrapping connector</td>
<td>x</td>
<td>6</td>
<td>x</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Assembly of windows, front and tail lights and direction indicator lamps</td>
<td>x</td>
<td>x</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>Assembly of pillars covers, trunk carpeting</td>
<td>x</td>
<td>12</td>
<td>x</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>Assembly of interior area with dashboard and pedals (as a ready-made element)</td>
<td>x</td>
<td>6</td>
<td>x</td>
<td>6</td>
</tr>
<tr>
<td>9B</td>
<td>Subassembly of interior module</td>
<td>x</td>
<td>x</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>Assembly of engine and exhaust system (as ready-made element)</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>10B</td>
<td>Subassembly of engine and exhaust system module</td>
<td>x</td>
<td>x</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Assembly of suspension (as ready-made element)</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>13</td>
</tr>
<tr>
<td>11B</td>
<td>Subassembly of suspension module</td>
<td>x</td>
<td>x</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Assembly of bumpers</td>
<td>x</td>
<td>x</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>14</td>
<td>Assembly of wheels</td>
<td>x</td>
<td>109</td>
<td>x</td>
<td>109</td>
</tr>
<tr>
<td>15</td>
<td>Assembly of seats</td>
<td>x</td>
<td>x</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>16</td>
<td>Assembly of steering wheel with air bag</td>
<td>x</td>
<td>12</td>
<td>x</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>Fuelling and filling with operating fluids</td>
<td>x</td>
<td>12</td>
<td>x</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>Assembly of doors</td>
<td>21</td>
<td>x</td>
<td>x</td>
<td>21</td>
</tr>
<tr>
<td><strong>TOTAL [s]</strong></td>
<td></td>
<td><strong>60</strong></td>
<td><strong>231</strong></td>
<td><strong>54</strong></td>
<td><strong>345</strong></td>
</tr>
</tbody>
</table>

Again, like in variant I, components loading/unloading time has been disregarded. For seven out of nineteen production workplaces parts were delivered directly from the buffer warehouses. For the other workplaces direct deliveries (four workplaces) or in-time deliveries with one logistic train were employed. The other logistic train in this case is redundant, which additionally eliminates the costs of its maintenance and servicing.
4. COMPARISON OF RESULTS

The analysis of parts delivery times indicates a considerable difference (32%) between variants I and II. The time of supply parts to each assembly stations depending on system which was used in simulations is presented in Figure 4.

In the Figure 4 by blue column the decreasing of the time of supply parts to assembly station is showed. The increasing of that time is marked by white column. It is noticeable, that for almost all assembly stations that time were lower. Significantly increased the time of supply tires to the station of No. 14. To achieve better results for supply tires, it is recommended to supply it from main warehouse by logistic train in JiT system. For that case the supply tires from buffer parts warehouse is not effective.

Figure 5 illustrates the comparison of the two variants including the duration time of direct deliveries from the main warehouse, in-time deliveries with a logistic train and direct deliveries from buffer warehouses located by the production line.

![Figure 4](image1.png)

**Figure 4** – Comparison of components delivery time to each stage in variants I and II

![Figure 5](image2.png)

**Figure 5** – Comparison of components delivery time to production line in variants I and II
JiS deliveries considerably reduce warehouse stock and the distance necessary to deliver components to the production line.

5. CONCLUSIONS

JiS deliveries require additional buffer warehouses, but they significantly reduce the stored stock and the distance necessary to deliver components to the production line. Moreover, they enable the reduction of the number of logistic trains, which reduces overall costs. It should be remembered that since in JiS delivery systems parts are delivered directly to the production line, in case of any delays in delivery from the outside stoppage of the production line may result. To avoid such a scenario, some stock of strategic components in the main warehouse is recommended.

6. REFERENCES