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“Station-Sequence” parts feeding in mixed models assembly: Impact of variations and industry 4.0 possible solutions

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Abstract: Parts feeding is a complex logistic problem, stressed by the increasing product variety that forces the assembly systems to manage a great number of models with a mixed model approach. In this context a possible parts feeding policy is the “station-sequence”, sequences of parts supplied to the assembly stations as function of the production models. This parts feeding policy can reduce stocks at the assembly stations, but offers potential production stops due to its low robustness. Different external elements can perturb the parts sequences (i.e. changing in production schedule, tasks times variation, variable supply lead times, etc.). The aim of this paper is to study, through a simulation study and a statistical analysis, the station-sequence part feeding policy considering its dynamic time-dependence the impact of the model mix and time perturbations on the system performance. Authors discuss the possible application of the real time events traceability, achievable through the I4.0 application, in order to mitigate the variability influence on the system performances.

Keywords: Parts feeding, Sequence, I4.0, real time, variations

1. INTRODUCTION

The increasing product variety and the affirmation of the assembly to order paradigm lead to design the assembly systems as mixed-model lines able of producing a great number of variants of the same base product. These assembly systems typically involve thousands of parts handled by the warehouse, i.e. supermarket, workers, during the assembly line feeding, and, then, by the station operators during the assembly tasks. The omission of a part makes the product defective and generates important time and productivity losses. Changes in the production demand, volume and mix, as well as the inclusion of new models and components strongly stress the part-feeding system. The definition of the part-feeding policy is a significant challenge in the modern assembly systems (Emde & Boysen, 2012). The modern pull-based part-feeding policy can summarized as:

- The kanban system which continuously refills the assembly stations through the pull kanban method using bins containing a fixed quantity of the same item, i.e. part (Kundu et al., 2019).
- The travel kit system, in which kits of the parts required to assemble the same product are prepared and follow the product through the assembly stations, i.e. travel kitting.
- The stationary kit, in which kits of the parts required to assemble different products are prepared for a fixed station.

A typical approach to perform the stationary kit is to create sequences of homogenous parts (in terms of typology and physical attributes) as consequence of the sequence of the models to assemble. This variant of parts feeding policy is called in the industrial jargon “Station-Sequence”. Figure 1 reports on the left the station-sequence concept and on the right side an industrial example.

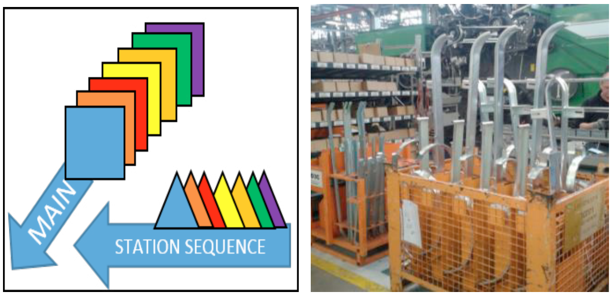

Fig. 1. Station-sequences

The station-sequence parts feeding policy relies on the derivation of transportation orders in a predictive manner based on the production sequence. This way, tours for the supply of the required parts are generated dynamically based on the predicted transportation orders. As presented by Battini et al. (2009), when evaluating the part-feeding policy to adopt, the total handling time taken by the different operators is the key parameter to consider. In the total handling time, it has to consider both the times at the warehouse, for the material preparation, and at the assembly stations, for the parts picking and placing. The time spent in handling parts increases moving from kanban to kitting system due to the increment of the number of picks required for the creation of the kits (Faccio, 2014; Rosati et al. 2013). On the other hand, the time spent in handling parts at the

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assembly station level decreases moving from kanban to kitting system due to the reduction of the amount of materials stored at the assembly station, which decreases the assembler working space, with positive effects on the station productivity (Hanson et al., 2012). The station-sequence feeding policy is interesting because it aims to reduce the handling time spent at the warehouse level, maintaining the advantage at the assembly station due to the reduction of the assembly worker space. In fact, while the positive of station-sequence is comparable to the kitting system in terms of inventory levels at the assembly stations, the picking time at the warehouse level decreases. Because of the parts belonging to the same station-sequence are of the same typology (i.e. motors), their locations are normally close one each other. This element has a strong positive effect on the picking time for the sequence creation because it decreases the picker covered distance that is the most part of the picking time. It can be reported the Tompkins et al. (2010) summarization about the composition of the manual picking time: 50% of the time is for travel activity, 20% is for search activity, 15% is for physical picking activity, and 15% is for other minor activities (picking tour setup, paper picking list printing, pick confirmation, etc.).

The station-sequence feeding policy suffers, on the other hand, of some drawbacks. They can be summarised as:

- The lack of flexibility respect to the change of sequence (and mix) of the models to assemble. If the stock of the station-sequence is low, the probability to stop the assembly as consequence of even one missing part increases when the sequence of the models to assemble change.
- The lack of flexibility respect to the assembly line cycle time variation. If the stock of the station-sequence is low, the probability to stop the assembly as consequence of even one missing part increases when the assembly line cycle time has significant variation.
- The lack of flexibility respect to the parts feeding period variation. If the stock of the station-sequence is low, the probability to stop the assembly as consequence of even one missing part increases when the parts feeding period has significant variation.

The aim of this paper is to analyse the station-sequence part feeding policy considering its dynamic time-dependence and analysing its performance as consequence of the time perturbations and of the model mix perturbations. This study is performed through a simulation study, as suggested by other contributes (Thürer et al., 2019). The main results are the quantitative definition of the main influencing factors and their impact on the system performance. Authors also discuss the possible application of the real time events traceability, achievable through the I4.0 application (Cohen et al., 2017), in order to mitigate the variability factors influence in the system performances. The paper is structured as follows. Section 2 reports the literature review, while section 3 describes the simulative models. Section 4 discusses the results and the main possibilities according the I4.0 applications, while conclusions are reported in section 5.

2. LITERATURE REVIEW

The main planning problems associated with high-variant mixed-model assembly can be divided according the time dimension. There are medium-long term problems, i.e. assembly line design, balancing, production management and planning, materials procurement. There are short time problems (Golz et al., 2012):

- Production sequencing: Determine the sequence of models for each production interval.
- Material flow control: Ensure the timely release of parts from suppliers and the in-time delivery of parts to the designated stations at the line.
- Resequencing: Reorder the production sequence in case of disruptions, for instance, final change of customers orders.

Even if the part-feeding policy is included in the material flow control, these three short time problems are strongly related one to each other (Azzi et al., 2012). Secondly, the dynamic time-dependence of these short time problems is evident. This aspect, as highlighted in the introduction section, is critical especially for the station-sequence policy. Many authors try to face the part-feeding problem from a “static” point of view, focusing of the parts attributes, their frequency of use, the related costs, without considering the dynamical aspect of the problem. From Bozer and McGinnis (1992) a great number of contributes are available. For a comprehensive literature review of parts feeding policy selection is possible to look at Kilic and Durmusoglu (2015). Hua and Johnson (2010) outlined qualitative factors driving the selection of the most appropriate parts feeding policy proposing the product and component volume, variety and size as main ones. Many authors, instead, try to propose quantitative comparison models for the correct parts feeding policy selection (Battini et al., 2009; Faccio 2014; Limère et al., 2015; Schmid and Limère, 2019). Looking at some recent contributes, Usta et al. (2017) presented a combined methodology to help decision makers, proposing, at first, a hierarchical clustering analysis and, then, an activity-based costing methodology to determine which system has a better performance. Caputo et al. (2018) explore the impact of parts features considering unit size and cost through a cost model for kitting, kanban and line stocking, focusing just on the feeding policy selection without any analysis on the warehouse design.

Some few studies try to integrate the part-feeding with the dynamical aspect of the problems. The first contribute is Choi and Lee (2002) who propose a two-stage heuristic solution procedure. In the first stage, transportation orders are determined based on expected part consumptions rates. Emde et al. (2012) consider a given production sequence and predetermined supply orders where the assignment of loads to tours which are operated under a fixed time schedule. Even Golz et al. (2012) highlight that the modern pull-based part-feeding policies consider to supply the parts, with predefined routes in a constant time interval. They, as the proposed study, consider buffer storages at assembly station frequently refilled with needed parts based on a given assembly sequence. They affirm that a specific difficulty of the station-sequence part feeding arising in high-variant mixed-model assembly, is the high variability of the required part quantities at the various line stations due to the ever changing daily production sequences. Moreover, the exact timing of the material supply is of utmost importance in order to avoid disruptions in the assembly process. Evidently, more effort in the part-feeding research field in considering the station-sequence parts feeding and its dynamic time-dependence is needed.

3. SIMULATION MODEL

The assembly feeding system is modelled through a simulation model. The considered parts feeding is the station-sequence. The aim of the simulation model is to analyse the assembly system performance, considering the station parts sequence as parts feeding policy, as consequence of the time perturbations and of the model mix perturbations. Because of, as reported in the literature review section, Golz et al. (2012) highlight the impact of models sequences variation as well as the exact timing variation of the material supply in the assembly system performance in case of station-sequence part-feeding policy, these parameters are considered as variables in the simulation model:

- The assembly line cycle time
- The parts feeding period
- The model mix sequences

The following assumptions are considered:

- The assembly system is a mixed model assembly line with a buffer between the parts feeding system and each assembly station where are stored the sequences of parts (station-sequences) (Figure 1).
- There is a buffer between each couple of assembly stations.
- The station-sequence follows the predicted main models mix of the assembly line.
- The assembly times are considered constant and equal to the average assembly line cycle time.
- The time distribution for the assembly line cycle time and for the parts feeding period is considered stochastic with uniform distribution.

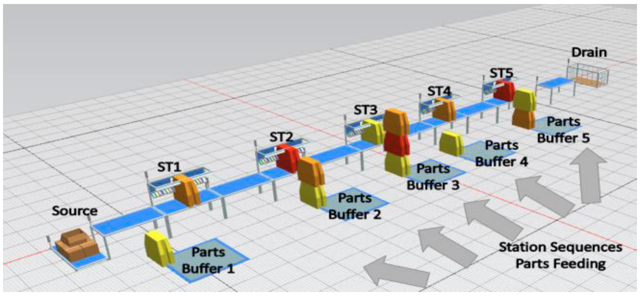

Fig. 1.Assembly system

The notations used in the simulation models are reported in Table 1. The simulation model considers 5 assembly stations with 3 models to assemble. The sequence for each station considers one part for each model to assemble. The models sequence is a variable of the simulation as well as the feeding time and the related time variation. Combining the different parameters reported in Table 2 has been derived a multi-scenarios analysis.

The simulations have been performed using Plant Simulation, (https://www.plm.automation.siemens.com).

The scenarios analysed are *I*=486. Table 3 reports an extract of the simulation results, where to each row corresponds a particular scenario according the reported input parameters highlighted in grey, and the output results highlighted in white.

The derived output parameters reported in Table 3 are calculated as:

$$PFQ_i = \frac{FP_i}{ALCT_i} \tag{1}$$

$$BS_i = \sum_n BS_{n,i} \tag{2}$$

$$MinBS = Min[BS_i] \tag{3}$$

$$MaxT = Max[THR_i] \tag{4}$$

$$W_i = \sum_n \frac{W_{n,i}}{N} \tag{5}$$

$$T_i = \frac{THR_i}{MaxT} \tag{6}$$

$$B_i = \frac{BS_i}{MinBs} \tag{7}$$

Table 1. Notations

Symbol	***Description***
$id=1,\dots I$	Simulation scenario ID Index
$n=1,\dots,N$	Assembly station index
$ALCT_i$	Assembly Line average Cycle Time of the scenario *i* [sec/piece]
$ALCTV_i$	Assembly line cycle time variation compared to the average assembly line cycle time of the scenario *i* [± sec/piece]
FP_i	Average parts feeding period of the scenario *i* [sec/sequence]
$PFCTV_i$	Parts feeding period variation compared to the average parts feeding period of the scenario *i* [±sec/sequence]
PFQ_i	Parts fed for each feeding period [parts/feeding period]
SEQ_i	Models sequence of the scenario *i*
$PFSEQ_i$	Parts feeding sequence of the scenario *i*
$BS_{n,i}$	Maximum parts quantity within the parts buffer for station *n* of the scenario *i* [pieces]
BS_i	Total Maximum parts quantity within the parts buffers of the scenario *i* [pieces]
$W_{n,i}$	Working time for station *n* of the scenario *i* [%]
THR_i	Total throughput during the simulation period of the scenario *i* [pieces]
$MinBS$	Minimum value of the total buffer content [pieces]
$MaxT$	Maximum value of the total throughput [pieces]
W_i	Average stations working time of the scenario *i* [%·100]
T_i	Relative total throughput [%·100]
B_i	Relative total Buffer Content [%·100]

Table 2. Simulation parameters

Parameter	*Value*	*Parameter*	*Value*
Simulation time	4 hours	*FP_i*	[180; 1800; 3600] sec/sequence
Assembly Stations	5 Stations	*PFCTV*	± [0; 30; 60; 900; 1800; 3600] sec/sequence
Models Number	3 Models	*$PFSEQ_i$*	[1M1, 1M2, 1M3]
ALCT	60 sec/piece	*SEQ_i*	[1M1, 1M2, 1M3]; [1M1, 1M2, 2M3]; [1M1, 1M2, 3M3]; [1M1, 2M2, 2M3]; [1M1, 3M2, 3M3]; Random
ALCTV	± [0; 30; 60] sec/piece		

Table 3. Extract of the simulation model inputs and outputs

id	ALCTi	ALCTVi	FPi	PFCTVi	SEQi	BS1i	BS2i	BS3i	BS4i	BS5i	W1i	W2i	W3i	W4i	W5i	THRi	BSi	PFQi	Wi	Ti	Bi
1	60	0	180	0	1 M1,1 M2,1 M3	4	4	4	4	4	99,6%	99,2%	98,7%	98,3%	97,9%	233	20	3	98,7%	1,00	1,00
2	60	30	180	0	1 M1,1 M2,1 M3	8	8	8	8	8	97,6%	97,2%	96,7%	96,3%	95,9%	229	40	3	96,7%	0,98	2,00
3	60	60	180	0	1 M1,1 M2,1 M3	13	13	13	13	13	95,6%	95,1%	94,7%	94,3%	93,9%	224	65	3	94,7%	0,96	3,25
10	60	0	180	0	1 M1,3 M2,3 M3	54	55	55	55	55	77,9%	77,9%	77,5%	77,1%	76,7%	182	274	3	77,4%	0,78	13,70
11	60	30	180	0	1 M1,1 M2,2 M3	80	81	81	81	81	66,7%	66,7%	66,7%	66,2%	65,8%	156	404	3	66,4%	0,67	20,20
12	60	30	180	0	1 M1,1 M2,3 M3	107	108	108	107	107	55,8%	55,8%	55,4%	55,0%	55,0%	130	537	3	55,4%	0,56	26,85
13	60	30	180	0	1 M1,2 M2,2 M3	41	42	42	42	42	83,3%	83,3%	82,9%	82,5%	82,1%	195	209	3	82,8%	0,84	10,45
14	60	30	180	0	1 M1,3 M2,3 M3	54	55	55	55	55	77,9%	77,9%	77,5%	77,1%	76,7%	182	274	3	77,4%	0,78	13,70
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

Considering the different simulation *I*, the main inputs of the simulation can be summarised as:

- *$ALCT_i$*, assembly line average cycle time.
- *$ALCTV_i$*, assembly line cycle time variation.
- *FP_i*, average parts feeding period.
- *$PFCTV_i$*, parts feeding period variation.
- *SEQ_i*, models sequences variation.

The main outputs of the simulation model can be summarised using the three a-dimensional parameters:

- *W_i*, average stations working time.
- *T_i*, relative total throughput.
- *B_i*, relative total buffer content.

From a conceptual point of view the best scenario would be the one where W is maximize (i.e. *W=1*), T is maximise (i.e. *T=1*), B is minimize (i.e. *B=0*).

A statistical analysis has been derived in order to understand the assembly system performance (*W, T, B*), as consequence of the time perturbations (*ALCTV, FP, PFCTV*) and of the model mix perturbations (*SEQ*).

A DOE analysis has been performed. The related Pareto chart shows the absolute values of the standardized effects from the largest effect to the smallest effect of the inputs to the different outputs *W, T*, *B* (Figures 2-4).

An ANOVA analysis has been performed. The related interaction plots determine the functional effect of each input variable and of their combinations to the output parameters *W, T*, *B* (Figures 5-7).

The relation between the three outputs parameters across the different simulations is reported in Figure 8 through a contour plot of *T* versus *B* and *W*.

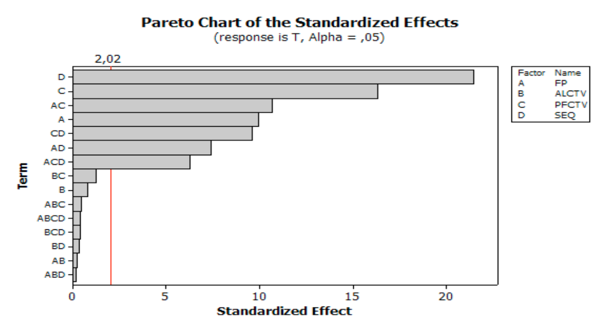

Fig. 2. Pareto chart of the inputs on *T*

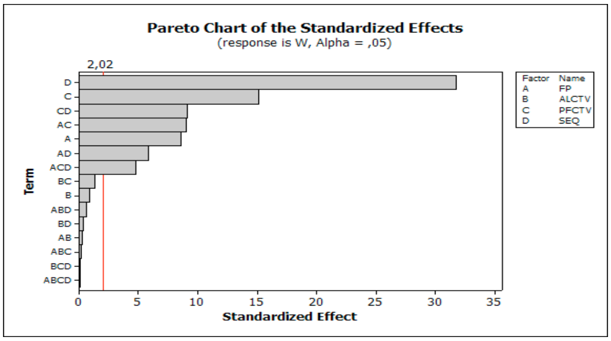

Fig. 3. Pareto chart of the inputs on *W*

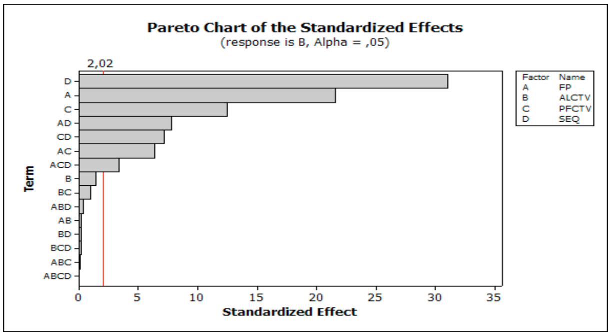

Fig. 4. Pareto chart of the inputs on *B*.

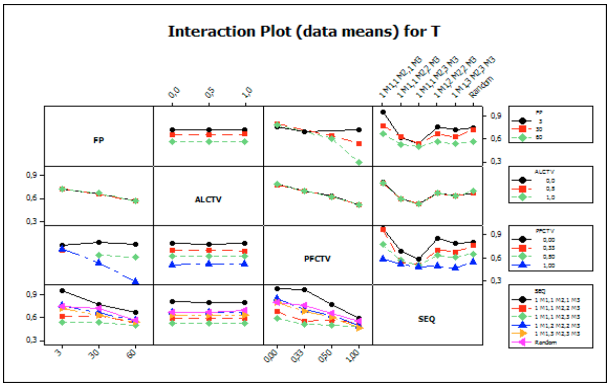

Fig. 5. Interaction plot of the inputs on *T*

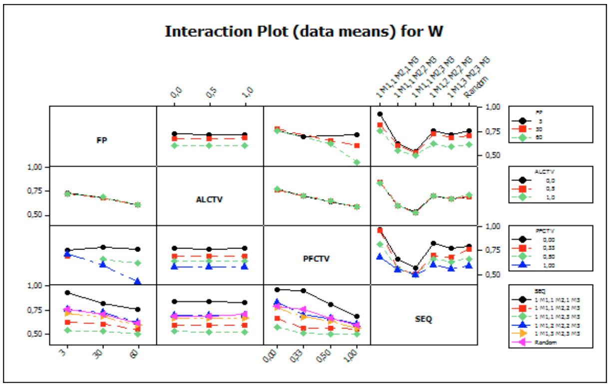

Fig. 6. Interaction plot of the inputs on *W*

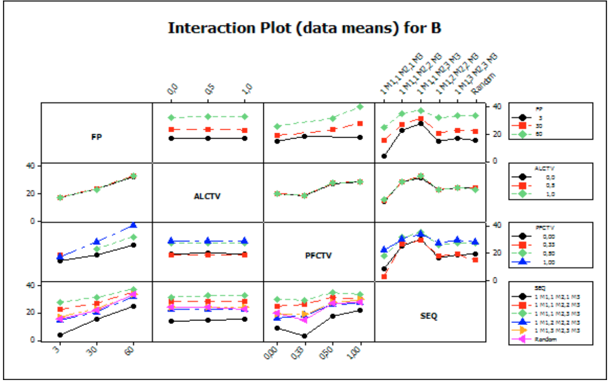

Fig. 7. Pareto chart of the standardized effect on *B*

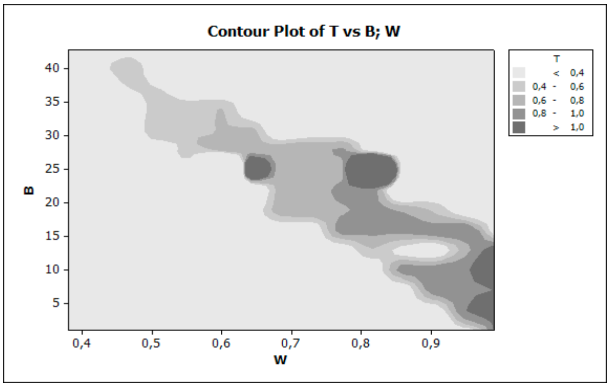

Fig. 8. Contour Plot of *T* versus *B* and *W*

4. DISCUSSION AND I4.0 POSSIBLE SOLUTIONS

Considering *T* (total throughput) it is interesting to notice that the main influencing variables are SEQ (models sequence variations) and *PFCTV* (parts feeding period variation) (Fig.2) with the trends reported in Fig.5. The more is their variation from the nominal value and the less is *T*. The combination of *FP (*average parts feeding period) and *PFCTV* is another influencing variable (Fig. 2) where the more is FP, the more is the effect of *PFCTV* on the *T* reduction (Fig.5). Considering *W* (average stations working time) the result is, as expected, similar to *T*, with *SEQ* and *PFCTV* as most influencing factors. Differently form T, the third is the combination of *SEQ* and *PFCTV* (Fig. 3) where the more is the *SEQ* variation, the more is the effect of *PFCTV* on the *W* reduction (Fig.6). Considering *B* (total buffer content), the main influencing variables are *SEQ*, *ALCTV* (assembly line average cycle time variation), *PFCTV* (Fig.4). The trends are reported in Fig. 6. At last is interesting to notice that, there is some scenarios where all the three outputs are almost maximise (*W* and *T*) and minimize (*B*) (*T* in dark grey and $B \approx 0, W \approx 1$). On the other hand, there are other scenarios where the highest values of *T (*dark grey) do not correspond on the minimum values of *B*. The impact levels of the different inputs on the different outputs are summarises in Table 4.

The models sequence variation at last has the most negative effect on the whole set of outputs reducing their values up to 50%. The variability of the market and the need to have an immediate response to changes in demand do not allow a freezing of the sequence of models for long periods. Consequently, it is important to have the actual progress of the products on the line and to take immediate decisions in the event of variations, reducing the time in which the system remains out of its nominal conditions. Using the Industry 4.0 traceability technologies any changes can be immediately identified. In Table 4 are described possible I4.0 solutions. For example, considering the most impacting input *(SEQ)* it could be possible:1-Sensorise assembly lines monitoring the real models sequences and parts sequences at assembly stations. 2-Compare real time models sequences versus the planned sequences. 3-Compare real time parts sequences versus the planned sequences. 4-Send real time information to parts feeder at warehouse highlighting differences. This allows immediate action to be taken to restore the system, minimizing the negative variations of *W, T, B*.

5. CONCLUSIONS

This paper analyse the “station-sequence” part feeding policy considering its dynamic time-dependence and analysing its performance as consequence of the time perturbations and of the model mix perturbations. This study is performed through a simulation study. The main results are the quantitative definition of the main influencing factors and their impact on the system performance. Authors also discuss the possible application of the real time events traceability, achievable through the I4.0 application, in order to mitigate the variability factors influence in the system performances. Authors are actually developing a first case study in an agriculture machines manufacturer. The experimentation testing, as well as the analysis selection and optimisation of the proper I4.0 traceability technology will be the next step of the research.

Table 4. Possible I4.0 solutions

INPUT VARIATIONS	OUTPUT	NEGATIVE IMPACT LEVEL	POSSIBLE I4.0 SOLUTIONS
SEQ	T	●●●●	1-Sensorise assembly lines monitoring the real models sequences and parts sequences at assembly stations. 2-Compare real time models sequences versus the planned sequences. 3-Compare real time parts sequences versus the planned sequences. 4-Send real time information to parts feeder at warehouse highlighting if real time models and parts sequences in the assembly line are different from planned ones. 5-Act as consequence.
	W	●●●●	
	B	●●●●	
PFCTV	T	●●●	1-Sensorise town trains monitoring real time positions across the routes. 2-Compare the real time positions with the planned positions according the parts feeding cycle time. 3- Send real time information to town trains operators 4-Act as consequence.
	W	●●●	
	B	●●	
FP	T	●●	1-Minimise feeding period reducing the town trains routes and increasing town trains numbers using Automated Guided Vehicles.
	W	●●	
	B	●●●	
ALCTV	T	●	1-Sensorise assembly lines monitoring the assembly stations takt time. 2-Compare the real time takt time with the planned takt time. 3- Send real time information to assembly stations. 4-Act as consequence.
	W	●	
	B	●	

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