MODELING AND SIMULATION OF AN ASSEMBLY LINE: A NEW APPROACH FOR ASSIGNMENT AND OPTIMIZATION OF ACTIVITIES OF OPERATORS

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ABSTRACT
In the paper we will suggest an approach based on modeling and simulation for the assignment of activities to the operators of a flexible assembly line. Thanks to the above approach, it will be possible to optimize the workload of each operator, in particular to reduce non-value and increase saturation. Through the adoption of a specific modeling logic, we can simulate lines with high flexibility of manufacturing and assembly, in various industrial sectors. Starting from the analysis of a real case and following an incremental approach, a simulation model has been realized, verified and validated, which allows to obtain useful information about: production mix; percentages of saturation; lead time and optimization of the assembly line.

Keywords: non-value added, saturation, lead time, productive capacity

1. INTRODUCTION
Thanks to the simulation of reality, it is possible to predict events, under specific conditions of using. Simulation is a powerful experimental tool that uses the possibilities offered by computer calculation. The "conceptual model" of the real system, is translated in a logical-mathematical procedure, permitting to understand how the system works (Law, and Kelton 1999).

The present paper proposes the development of a virtual model simulating an assembly line. A simulation model is created, verified and validated, in order to obtain useful information about:

- productive capacity;
- partial and total lead time;
- percentage of saturation, Value Added (VA) and Non-Value Added (NVA), for each worker and station;
- line optimization.

The virtual model is the evolution of a study carried out previously, considering few stations of the same line (Falcone and others 2010) (Falcone and De Felice 1998). During the development phase, an important goal has been pursued: the possibility to use and change the model without knowing the creation logic. It is possible to change input parameters through a database, which contains details about operations. Furthermore, a timetable was created with the times of the various operations along the line, which feeds the simulation model. Through the connection between the database and the physical model and the introduction of constraints assigned to the various operations, it is possible the construction of a simulation model able to reproduce the real productive line. The goals are the identification and optimization of the line in terms of minimization of NVA and no-saturation of operators.

2. STUDY OF THE OPERATIVE TIMES
The production mix consists of two models of the same product, realized along an assembly line, with many workstations and a big number of manual operations, performed on the front, back, the right and the left side of the product. If the operations are performed on one or both sides, in the stations we will find, respectively, one or two operators; if we provide also the operations on the front or back of the product, there will be another operator. Each product is labeled with information about the components required and the correct assembly sequence. For both models there is a number of optional components that can be installed on the product, so we have more configurations of the same model. For each operation the total time assigned is characterized by five aliquots: two times for the activities adding value to the product (product transformation and quality control) and three aliquots that do not add value to the product (supplying or picking, walking and similar activities).

The above subdivision allows evaluating VA and NVA for each operator and workstation. During the fixed advancing time of the line, linked to the takt time, the operators must perform all the operations assigned to him in his workstation. The difference between the total cycle time and the whole working time, allows evaluating no-saturation of operators.

3. VALUE ADDED (VA) AND NON-VALUE ADDED (NVA)
In economics, the value added (also abbreviated VA), or capital gains, is the measure of the increased value resulting in the production and distribution of goods and

services, thanks to factors of production: capital and labor. The difference between the value of goods and services produced and the value of goods and services purchased for the production process is the value added.

Each company has adopted strategies to maximize VA and minimize non-value added (also abbreviated NVA), which represents the decrease in value due to the time spent to perform all the activities that the customer does not see and therefore is not willing to pay.

In order to reduce NVA, the process manager has to ensure saturation of the operators, splitting operations to the operators. In practice, he allocates the operations in a single workstation, taking into account the total number of activities of the work shift, according to the production mix (Falcone and De Felice 2007). The aim is to combine tasks, in order to achieve the total number of minutes of work in one shift. This aim is simple, but not obvious, in fact almost no one can ever saturate a worker for the exact duration of an entire shift, but only for a shorter time.

The difference between the work shift time and the result reached is the no-saturation: the minutes paid to the operator, while he doesn't "work" because he has nothing to do and obviously represents a loss.

The manufacturing cycles include information about operation allocated in different workstations, with an indication on how much of the total time is made of real assembly or manufacturing (value-added activities) and how much of supplying, moving, picking and so on (non-value added activities) (Baracchino 1989) (Ciappei 1988). Using these data it is possible to analyze NVA activities, searching for possible improvements. The approach adopted so far is mainly related to the experience of the process manager and requires to start over according to any change of production. For these reasons it's important to look for tools and procedures able to accelerate and objectify all the actions of optimization described.

4. VIRTUAL MODEL

The present work takes into consideration a previous work of the same authors. The model was previously realized for only two workstations, subsequently extended to the whole production line, with the same programming logic. The old simulation model is shown in the figure n. 1. The model developed initially, allowed a manual optimization, useful in the case of a little number of stations. Instead, in the case of a big number of stages, an improvement of the model is required.

Figure 1: Old simulation model view

An important aspect of the programming logic is the separation between the simulation model and the input data-base, more complex the first and very simple the second. In fact it is possible to change input data simply acting on an Excel table, shown in the figure n. 2, even without any simulation knowledge.

CADENZA 1.06		TEMPI CICLO				
	OPERAZIONI	TRASFORMAZIONE [min]	QUALITA' [min]	VARIE [min]	RIFORNIMENTO [min]	WALK [min]
STAZIONE 7 LATO DX	292	0.09	0.00	0.00	0.02	0.01
	26010	0.04	0.00	0.00	0.01	0.00
	7144	0.00	0.08	0.00	0.02	0.03
	7187	0.09	0.00	0.02	0.04	0.01
	7407	0.06	0.00	0.00	0.00	0.00
	7466	0.11	0.00	0.01	0.00	0.01
	7488	0.09	0.00	0.00	0.00	0.00
	7490	0.18	0.00	0.00	0.00	0.01
	7160	0.00	0.13	0.04	0.03	0.01
	7172	0.15	0.00	0.00	0.00	0.01
STAZIONE 7 LATO SX	294	0.04	0.00	0.00	0.01	0.00
	520	0.10	0.00	0.00	0.02	0.01
	26020	0.04	0.00	0.00	0.01	0.00
	7122	0.09	0.00	0.00	0.02	0.01
	7124	0.03	0.00	0.00	0.02	0.00
	7146	0.00	0.08	0.00	0.02	0.03
	7204	0.06	0.00	0.00	0.02	0.00
	28020	0.05	0.00	0.00	0.00	0.00
	7444	0.03	0.00	0.05	0.00	0.01
	7470	0.11	0.00	0.01	0.00	0.01
	7494	0.09	0.00	0.00	0.00	0.01
	7162	0.00	0.13	0.04	0.04	0.01
ST. 8	21564	0.00	0.00	0.00	0.05	0.04
	21736	0.00	0.00	0.00	0.04	0.17
	5032	0.05	0.00	0.00	0.03	0.02
	7092	0.35	0.00	0.00	0.12	0.06

Figure 2: Time Table of Operations

But, if we need to modify operations position along the line, in order to consider different constraints, a simulation model redefinition is necessary. Therefore, the model improvement requires the creation of a single modular workstation, in which a flexible number of activities is included, using many "labor machine" icons, at the beginning not initialized. Subsequently, the whole assembly line can be modeled through the duplication of standard workstations, opportunely linked together (Benjaafar 1992). In each workstation, the particular operation icon will be activated or not by the dynamic input database, including all the operations of all product models, characterized by different combinations of optional components (Fig. 3).

A particular codified label related to the specific product under production, allows understanding which records of the dynamic database have to be considered, determining the path of the product in the simulation model.

Figure 3: Extended model

Therefore the programming logic is the following: the product label defines which operations are required, subsequently some records of the database are identified and finally some labor machines of the model activated, able to read input data directly from the data base (Fig. 4).

In this way, when we have a new product, we don't need to modify the virtual model but we can act outside the model and inside the database, in which there are all production times.

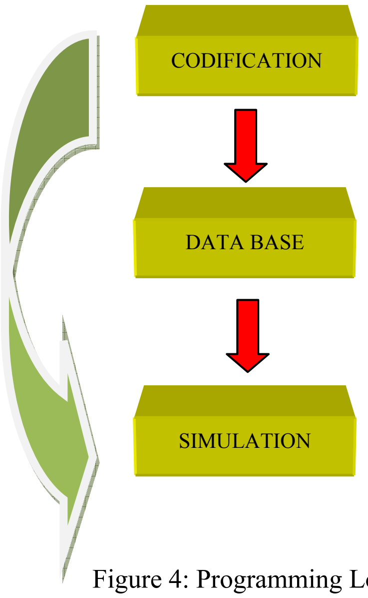


Figure 4: Programming Logic

Each record of the database includes the code of a particular operation and the relative five time aliquots.

5. OPTIMIZATION PHASE

At this point the optimization phase starts. In order to increase the saturation of each operator and station, the process manager has to assign operations to the available operators in different stations, according to the production order. Thanks to the improvement of the model, it is possible an automatic assignment using software tools acting directly on the simulation model rather than on the database.

The optimization step has to consider many variable constraints, in particular:

- Technological constraints: they are related to the nature of the technological cycle, conditioning the correct sequence of operations.
- Ergonomic constraints: they are related to the ergonomics of each workstation. Some operations can be performed only in particular stations.
- Equipment constraints: they are related to the resources of each station. Some operations may require special equipments.
- Constraints of space: Some tasks require the physical space for operators to perform their duties, according to ergonomic constraints too.

In order to respect the above constraints, some records in the database, are linked to "fixed" positions in the model. Subsequently the optimizer can't move the corresponding operations, in order to balance the assembly line and reach particular goals. Figure 5 shows the general structure of the model.

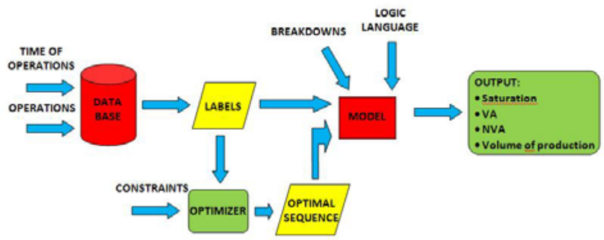
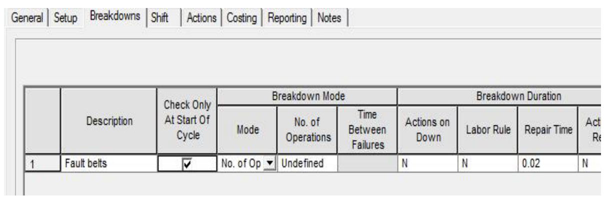


Figure 5: General structure of the model

Another important change of the model, has been the introduction of downtimes, always present in the case of manual or automatic assembly lines. Basing on the study of the real failure rates, it is possible to enter configuration data in each labor machine of the simulation model (figure 6).



General | Setup | Breakdowns | Shift | Actions | Costing | Reporting | Notes

	Description	Check Only At Start Of Cycle	Breakdown Mode			Breakdown Duration			
			Mode	No. of Operations	Time Between Failures	Actions on Down	Labor Rule	Repair Time	Act Re
1	Fault belts	☑	No. of Op	Undefined		N	N	0.02	N

Figure 6: Table of downtimes

The last extension of the model previously made, has been the introduction of probabilistic times. In fact, an operator is not able to perform the same task always in the same time (Zhou and Venkatesh 1999). So, deterministic times have been replaced by probabilistic ones, characterized by a particular probability distribution.

All the modifications proposed, permits to obtain a more realistic model of the studied flexible line (Raouf and Ben Daya 1995).

6. MODEL VERIFICATION AND VALIDATION

Many verification and validation activities occurred (Tocher 1967). Firs of all, we verified the codification labeling procedure, in order to identify in the whole timesheet, all assembly operations of a particular product.

Then, the production quantity both in the case of deterministic and probabilistic times, with and without breakdowns, has been compared with real data. During 450 production minutes for each working shift, with a production frequency of 1.06 minutes, 425 products are realized, according to the real production and its standard deviation.

We have also verified the impact of changes of times on the operator saturation. See the following example.

Figure 7: Saturation data before change

Figure 8: Saturation data after change

Finally, after the production sequence optimization, we have verified that the allocated activities were realized correctly on the product in the right station by the right operator, testing the model flexibility.

7. CONCLUSIONS

This work concerns the development of a simulation model of an assembly line. The programming logic adopted shows characteristics of modularity and generality which could be extended to different production systems (Rumbaugh and others 2005). By using commercial simulation software, a virtual model has been created and gradually improved, making it closer to reality, as well as more complex. The end result reached is a flexible virtual model that can simulate and optimize the operating conditions of the production line examined. The model allows seeing the number and types of products made in a specific period of time, the percentages of VA, NVA and the saturation rate of each operator or workstation, rather than the whole line. An external data base was realized, usable by anyone, even inexperienced against the simulation software. It is possible to modify the processing times and consequently the location of each activity along the line, simply clicking on the value and changing the variable initialization. This function allows you to obtain an increase in saturation of the operators, taking into account the process constraints, technological, ergonomic and others. So, you can see the impact of any change introduced, through an extensive reporting on working and crossing times, VA and NVA activities, saturation of operators and so on. Finally, the introduction of an external database, collecting data of all operations, permits to manage the production flow easily. Through the use of an optimizer, the operations are moved from one station to another, in order to achieve the fixed goals. For example, you could optimize the production flow in order to saturate the operators as much as possible; or you could minimize any time spent in activities that do not add value to the product. The general approach followed and simulation model realized could be friendly applied in different sectors and industrial contexts (Dallari and Marchet 2003).

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