Abstract
This work proposes the use of a capability method in order to carry out techno-economic analysis of production processes, modules and robotic production lines. By determining the actual performance of serviceable parts and products, one can identify bottlenecks and locate areas in need of expansion in a given production program.

Keywords: Techno-economic analysis, Capacitive Method, Computer Integrated Manufacturing Systems, Optimization.

Introduction
Techno-economic analysis is important for every kind of manufacturing systems. This field is becoming increasingly essential due to the requirements for capital investment on the one hand, and the increasing complexity of technical specifications of manufactured products on the other hand.

Robotic manufacturing systems possess both characteristics, i.e., they involve large capital investments as well as inherent need for control over a wide range of technical specifications.

A large variety of engineering solutions can be applied to the design of robotic modules and systems, especially in the initial, conceptual stage. It is imperative to devise and compare different schemes for possible implementations early on, because the cost of applying design modifications increases exponentially as the project progresses. There are many criteria that can be compared, and various ways in which these criteria can be prioritized.

An important consideration in the selection of any effective engineering solution is to ensure the quality of the process in terms of system performance while minimizing the costs. To this end, researchers have worked intensively towards developing different methodologies [1,3,5], some of which have more general applications [6,7,8], while others are more specialized [2,4].

The purpose of this study is to demonstrate the extent in which the capacitive method is applicable to automated production sites and computer-integrated manufacturing (CIM) systems.

Theoretical foundations of capacitive methods for techno-economic analysis
The capacitive method is used to evaluate:

- The quantity of manufactured elements (units, binders and final products) which are produced by each workstation in an automated conveyor production line.
- The movement of the load and the flow of transport.
- The production rate of the entire automated line.

Figure 1 is a sample assembly line that includes storage, transportation and four technological machines. Let us examine the performance of M1 - the first machine. We will assume for our example, that upon examination it was found that M1 is capable of producing 500 units/week in a given period of time. In this example, the production line is expected to produce 1,000 units/week of those units in about that time, which means that under these specifications the workstation will require two identical machines of type M1 to produce the desired output.

One can therefore use the following formula (1) to calculate the number of units/time that can be produced (or processed) by each element of the system (be it robot, machine, peripheral device or other mechanism) in a given period of time (e.g., 1 week):

\[
MC = RR \times WT \times U \text{[units/week]}
\]

Where:
The application of the capacitive method for optimizing a production process in an automated work cell (AWC) and CIM system (Figure 2)

MC (Machine Capacity per week) \([\text{units/week}]\) is the production capacity of the machine (workstation) in a specific period of time (in this case 1 week);

RR (Run Rate) \([\text{units/h}]\) – the production norm, i.e., the quantity of units that can be produced by the machine (workstation) in a specific period of time (in this case per hour); it is specified by means of chronometrization;

匀x x 0.3 = 1249.92 (1250) \([\text{units/week}]\);
MC(bad) = 1,344 × (1 − 0.93) = 94.08 (94) [units/week].

**Example of the capacitive method in a CIM system with three workstations (WSt)**

In the following example we consider an automated working system consisting of a storehouse, a production workstation (sawmill, servicing robot, shop for completed units) and a workstation for quality control of finished units (geometrical shapes) received from the sawmill.

The three workstations (Figure 3) of the CIM system have the following specifications:

![Figure 3: Graphic representation of a CIM system with three workstations](image)

WS1 – Storehouse: automated storage and retrieval system (ASRS), with 36 rack cells.

WS2 – FMS workstation for sawmill setup, consisting of a Scorbot-ER V plus robots servicing a CNC sawmill “Prolight 1000”.

WS3 – Workstation for product quality control (QC), consisting of a Scorbot-ER IX robot and a webcam setup for visual control (to determine whether each unit is “good” or “bad”).

Conveyor – closed-loop transport conveyor with eight free-moving pallets, providing transport services to all workstations.

The tests were carried for two different production process scenarios:

Machine time for all workstations is considered to be the same, derived from the longest duration (slowest station)

System parts are manufactured with different durations of machine time, and this is taken into consideration.

Five consecutive trials were carried out, each of which lasted 1 hour (WT = 1 [h / week]).

In order to calculate the actual utilization of the system, \( U \), operational specifications were taken from the operational planning documents and from gathered maintenance records of the preceding calendar year.

The production capacity, \( MC \), of each workstation was calculated as an arithmetic average across the measurements during the five trials. The results are presented in tabular form in Table 1 for the first test and Table 2 for the second test.

In addition, the bar graphs and pie charts below (Graphs 1–4) show the production capacity for each component in the production process.

Both tests demonstrated that the duration of the technological operations in the second workstation (WS2) delays the entire production process. In practice, this is a bottleneck in the production process (predictable result since the sawmill process is obviously the slowest).

| Object to Object | No. of stages | SPT (wt) | JST (wt) | A | B | C | D | U | WT (hour) | B | MC (unit/week) | MC - Average (unit/week) |
|------------------|---------------|----------|----------|---|---|---|---|---|-----------|---|---------------|------------------------|
| ASRS to WSt2     | 1             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 2             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 3             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 4             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 5             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 6             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 7             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 8             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 9             | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 10            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 11            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 12            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 13            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 14            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 15            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 16            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 17            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 18            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 19            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |
|                  | 20            | 5        | 5        | 5  | 5  | 5  | 5  | 1  | 12        | 9.6 | 9.6          | 9.6                    |

Thus, optimizing the production process would require an investment towards replacing the existing technological machine with a higher-capacity machine, or increasing the number of machines at the slower workstation, which in turn would necessitate appropriate adjustments to the work plan, layout and program commands.

In this example, the three station process is trivial, and the results predictable. The propose of the tests were to demonstrate the possibility of using the capacitive method for optimization on CIM system, and once it is established that it is in fact possible, more complex scenarios can be analyzed in order to achieve non-trivial optimizations.
Conclusion

The application of the capacitive method for technical and economic analysis of robotized and automated production systems demonstrates that the method is both pragmatic and straightforward.

The application described in section 5.2 proves the accuracy of the method and its suitability for analysis of high-technology production lines and systems, in cases where it is necessary to evaluate the production capabilities of the installed equipment. This evaluation is most often necessary when new tools are implemented in the production process.

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