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Application of a Capacitive Method for Technical and Economic Analysis for Process Optimization in Computer-Integrated Manufacturing (CIM) Systems

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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 requires 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):

(1) $$MC = RR \times WT \times U \text{ [units/week]}$$

Where:

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

RR (Run Rate) [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;

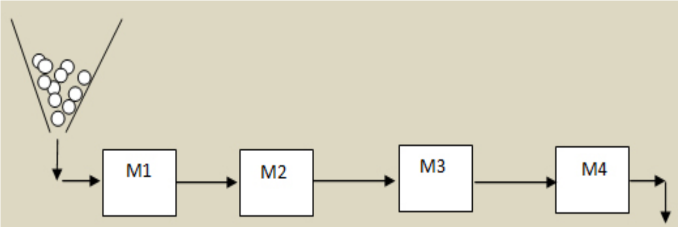


Figure 1: General example of an assembly line with a storage system

WT (Work Time per week) [h/week] – the total possible number of working hours during the examined week;

U (Utilization) [%] – actual machine/workstation utilization.

The utilization *U* of the machine is a function of the machine's availability (*A*) and the protective capacity (*PC*) of material and labor force, as seen in the following formula:

(2) $U = A - PC$ [%]

Where:

A [%] is the actual availability of equipment, facilities, materials, time, etc. for full utilization and production. In most cases this value is a prediction (estimated according to prior documentation) and differs from the "true" availability.

PC [%] is the protective capacity of material and labor force for the specified work time.

The actual availability *A* is a function of the entire period of time allocated for production (100%), in addition to *SDT* (Scheduled Down Time) designated in advance for planned maintenance, and *USDT*(Unscheduled Down Time) the time in which work is not carried out because of unforeseen circumstances.

(3) $A = 100 - (SDT + USDT)$ [%]

The following factors influence the protective capacity, *PC* [%], of material and labor force for the specified work time:

The machine (workstation) is suitable for production but is not operational owing to the following factors (**a** and**b**):

a - non-availability of materials;

b - lack of appropriate labor force;

(4) $PC = a + b$ [%]

Taking into account all the above mentioned factors, the real utilization of the machine (workstation) is calculated according to the following dependency:

(5) $U = 100 - [SDT + USDT + (a + b)]$ [%]

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

Figure 2: Automated Work Cell (AWC) with a robot and a computer numerical control (CNC) machine

Example of an AWC

Given the following set of parameters:

$SDT = 5\%$; $USDT = 5\%$;

$a = 5\%$; $b = 5\%$;

$PC = a + b = 10\%$;

The formulas yield the following result:

$A = 100 - (SDT + USDT) = 100 - 10 = 90\%$;

$U = A - PC = 90 - 10 = 80\%$;

$MC = RR \times WT \times U = 10$ [units/hours] x 168 [hours/week] x 0.80 = 1,344 [units/week]

With the above set of parameters, **the production rate of the AWC is calculated to be 1,344 units per week**.

In order to use the capacitive method to fully reflect system performance, the quality of the manufactured products must also be taken into consideration. In order to quantify the quality of the manufactured products and the quantity of manufactured waste, the following term is defined:

Production quality: *Y* (Yield) [%]- the percentage of quality units produced by a particular machine or automated module, out of the total number of units produced by that module.

The term *Y*determines the values of two additional parameters that influence the production rate of the AWC: **positive capacity** (*MC(good)* [units/week]) **and negative capacity** (*MC(bad)* [units/week]).

The positive capacity of the machine or AWC (*MC(good)* [units/week]) is the number of quality units produced per week, and it is calculated as follows:

(6) $MC(good) = MC \times Y$ [units/week],

The negative capacity of the machine or AWC (*MC(bad)* [units/week]) is the number of faulty units produced and is represented by the following mathematical expression:

(7) $MC(bad) = MC \times (1 - Y)$ [units/week].

If the AWC in our example produces 1,344 unitseach week, and **93%** of them are suitable, then:

$MC(good) = 1{,}344 \times 0.93 = 1249.92$ (1250) [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

WSt1 – Storehouse: automated storage and retrieval system (ASRS), with 36 rack cells.

WSt2 – FMS workstation for sawmill setup, consisting of a Scorbot-ER V plus robots servicing a CNC sawmill "Prolight 1000".

WSt3 – 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 (WSt2) 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 check	No .of checking	SPT [%]	USPT [%]	A [%]	a [%]	b [%]	PC [%]	U [%]	WT [h/week]	RR [unit/h]	MC [unit/week]	MC - Average [unit/week]
	ASRS to ST2	1	5	5	90	5	5	10	80	1	12	9.6	
		2	5	5	90	5	5	10	80	1	12	9.6	
A		3	5	5	90	5	5	10	80	1	12	9.6	9.6
		4	5	5	90	5	5	10	80	1	12	9.6	
		5	5	5	90	5	5	10	80	1	12	9.6	
	FMS ST2 Robot + CNC Machine	1	5	5	90	5	5	10	80	1	4	3.2	
		2	5	5	90	5	5	10	80	1	4	3.2	
B		3	5	5	90	5	5	10	80	1	4	3.2	3.2
		4	5	5	90	5	5	10	80	1	4	3.2	
		5	5	5	90	5	5	10	80	1	4	3.2	
	Conveyor from ST2 to ST3	1	2	2	96	1	1	2	94	1	4	3.76	
		2	2	2	96	1	1	2	94	1	4	3.76	
C		3	2	2	96	1	1	2	94	1	4	3.76	3.76
		4	2	2	96	1	1	2	94	1	4	3.76	
		5	2	2	96	1	1	2	94	1	4	3.76	
	QC ST3 Robot + Camera	1	5	5	90	4	4	8	82	1	4	3.28	
		2	5	5	90	4	4	8	82	1	4	3.28	
D		3	5	5	90	4	4	8	82	1	4	3.28	3.28
		4	5	5	90	4	4	8	82	1	4	3.28	
		5	5	5	90	4	4	8	82	1	4	3.28	
	Conveyor from ST3 to ASRS and import in ASRS	1	5	5	90	5	5	10	80	1	4	3.2	
		2	5	5	90	5	5	10	80	1	4	3.2	
E		3	5	5	90	5	5	10	80	1	4	3.2	3.2
		4	5	5	90	5	5	10	80	1	4	3.2	
		5	5	5	90	5	5	10	80	1	4	3.2	

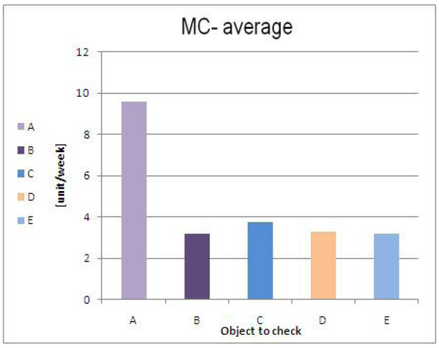
Table 1: Results for First Test

	Object to check	No .of checking	SPT [%]	USPT [%]	A [%]	a [%]	b [%]	PC [%]	U [%]	WT [h/week]	RR [unit/h]	MC [unit/week]	MC - Average [unit/week]
	ASRS to ST2	1	5	5	90	5	5	10	80	1	12	9.6	
		2	5	5	90	5	5	10	80	1	12	9.6	
A		3	5	5	90	5	5	10	80	1	12	9.6	9.6
		4	5	5	90	5	5	10	80	1	12	9.6	
		5	5	5	90	5	5	10	80	1	12	9.6	
	FMS ST2 Robot + CNC Machine	1	5	5	90	5	5	10	80	1	9	7.2	
		2	5	5	90	5	5	10	80	1	4	3.2	
B		3	5	5	90	5	5	10	80	1	7	5.6	6.08
		4	5	5	90	5	5	10	80	1	8	6.4	
		5	5	5	90	5	5	10	80	1	10	8	
	Conveyor from ST2 to ST3	1	2	2	96	1	1	2	94	1	9	8.46	
		2	2	2	96	1	1	2	94	1	4	3.76	
C		3	2	2	96	1	1	2	94	1	7	6.58	7.144
		4	2	2	96	1	1	2	94	1	8	7.52	
		5	2	2	96	1	1	2	94	1	10	9.4	
	QC ST3 Robot + Camera	1	5	5	90	4	4	8	82	1	9	7.38	
		2	5	5	90	4	4	8	82	1	4	3.28	
D		3	5	5	90	4	4	8	82	1	7	5.74	6.232
		4	5	5	90	4	4	8	82	1	8	6.56	
		5	5	5	90	4	4	8	82	1	10	8.2	
	Conveyor from ST3 to ASRS and import in ASRS	1	5	5	90	5	5	10	80	1	9	7.2	
		2	5	5	90	5	5	10	80	1	4	3.2	
E		3	5	5	90	5	5	10	80	1	7	5.6	6.08
		4	5	5	90	5	5	10	80	1	8	6.4	
		5	5	5	90	5	5	10	80	1	10	8	

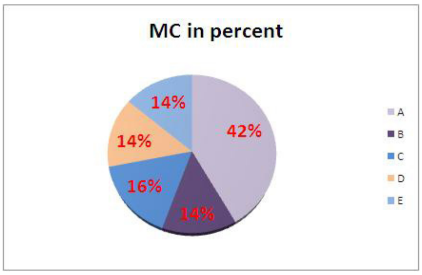
Table 2: Results for Second Test

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.

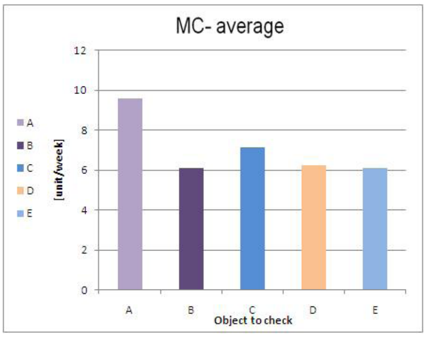
In this example, the three station process is trivial, and the results predictable. The propose of the tests were to demonstrate the possibility of using the capacitive method for optimization on CIM system, and once it is established that it is in fact possible, more complex scenarios can be analyzed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



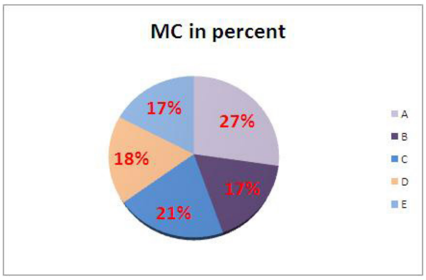
Graph 1: Production capacity in average



Graph 2: Production capacity in percentage



Graph 3: Production capacity in average



Graph 4: Production capacity in percentage

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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