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An application of collaborative robots in a food production facility

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Abstract

Despite the food industry being a leading sector of the European economy, the level of penetration of automation is still low. The main reasons lie on the small margin of food items which does not encourage technological investments, the extremely spread vendors market i.e. mostly small and medium enterprises, and the high level of flexibility and care required to handle food products along production, packaging, and storage operations. Nevertheless, the advent of collaborative, small and flexible robots provides great opportunities for the design and development of new effective processes integrating the human flexibility with the efficiency of automation.

This paper explores the impact of adopting collaborative robots in the food catering industry, by illustrating a case study developed for the end-of-line of a catering production system. A generalizable methodology is proposed to support the study of the technical and economic feasibility of the implementation of such technology.

This methodology is intended to support managers of the food industry to analyse the constraints that limit the automation of a process and to measure the expected performance of the system in terms of throughput, ergonomics and economic benefits resulting from the adoption of collaborative robots.

Keywords: Collaborative robots; Food industry; Industry 4.0; Production automatization; Feasibility analysis

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Nomenclature and Notation

t^{α}_{pick}	Time to pick a primary package and put it into a secondary package (sec)
t^{α}_{lab}	Time to label a primary package (sec)
t^{β}_{pick}	Time to pick an empty secondary package and put it into a filling buffer (sec)
t^{β}_{dep}	Time to put an full secondary package into a tertiary package (sec)
t^{β}_{lab}	Time to label a secondary package (sec)
t^{γ}_{pick}	Time to pick a full tertiary package from the filling buffer and move it to storage/shipping area (sec)
t^{trav}	Travelling time to supervise production tasks (sec)
t^{setup}	Time spent for lot setup (sec)
t^{idle}	Idle time of the operator waiting for packed meals at the end-of-line (sec)
$v^{\alpha,\beta}$	Number of primary packages per secondary package
$v^{\beta,\gamma}$	Number of secondary packages per tertiary package
l^{α}	Number of primary packages per production lot
l	Number of lots per working shift
d	Number of working shifts per year
c	Cost of an operator for a working shift (€)
s^{task}	Space on the facility layout occupied by the task to be automated (sqm)
s^{Cobot}	Space occupied by the Cobot and the automated system (sqm)
T^{Layout}	Temperature of the area where to task to be automated is performed (°C)
$T^{Cobot(+/-)}$	Safe/nominal Cobot working temperature (°C)

1. Introduction

Contract catering industry is responsible for producing ready-to-eat meals and their supply to schools, hospitals and private companies [1]. Such meals must be cheap [2], customized (i.e. diets and functional foods) and tightly controlled for compliance with safety and quality standards [3,4]. The processing phases must be optimized and monitored to avoid food contamination and losses of quality (i.e. HACCPs) [5]. As a consequence, catering operations are characterized by the trade-offs between costs, time and quality [6].

A catering facility (also named Ce.Ki.) produces lots of meals (e.g. 10.000 meals per day) every day [7]. The packed meals are refrigerated and stored into climate-controlled chambers for 3-4 days rather than directly shipped to multiple points of consumption [8]. The Ce.Ki. layout is configured in different departments, each devoted to a specific task (e.g. boiling, cutting, baking), and the end-of-line area is the bottleneck of the entire process. In this area, cooked meals are weighted, packed (in the proper combination of primary, secondary and tertiary package), labeled and consolidated for delivery tours toward the points of consumption [9]. All these tasks (except for thermo-sealing and labeling) are manual. The ergonomic load for the operators resulting by these tasks i.e. putting packed meals into plastic crates, handling crates onto roll-container, is light but frequent. The speed of the packing line is driven by the production throughput and affected by the current layout and the available handling equipment. Each crate is filled with meals of the same production lot, and many lot changes per day may increase the complexity, the effort of pick-and-place activities, errors and space requirements as well.

Technological advances of the collaborative robots (Co-Bot) sector provide new opportunities for those production environments where the presence of the operator cannot be avoided but many operations are highly repetitive and can be performed by automated manipulators [10,11]. The adoption of Co-Bots can be encouraged in presence of standard handling units (e.g. package of defined shape and reduced variability) [12], when the maximum load is less than 10 kg and for products with surfaces and materials that are suitable for picking operations.

This paper presents a study of the technical and economic feasibility for the adoption of a Co-Bot to pack finished meals in a catering production facility. The focus of this paper is neither on the control of the Co-bot nor on the characteristics of the technology, but on a methodology used to assess the technical and economic feasibility of replacing manual activities with automated and collaborative solutions, assessing the so-called fitness for automation [13]. Examples of assistant approaches for the system design of collaborative robots installation are provided in recent papers [14,15]. The remainder of this paper is organized as follows. Section 2 describes the methodology. Section 3 presents its application a case study from the food industry, while Section 4 concludes the paper discussing on opportunities for the penetration of collaborative robots in this and other industrial sectors.

2. Methodology

This section describes a practical methodology that investigates the technical and economic feasibility of implementing collaborative automated technology in manual handling/production processes. Despite being generalizable, the methodology illustrated in Fig. 2 is hereby intended and exemplified for the adoption of a Co-Bot to replace the manual pick-and-place tasks of some operators at the production end-of-line.

When approaching to the automatization of manual tasks, the production managers have to deal with concurrent issues and scopes as the improvement of the production throughput, the reduction of operators' idle time and of the ergonomic loads as well. First, an accurate observation of the production process and the facility layout is recommended with the attempt to identify the most promising manual tasks for the automatization project. The characteristics of the Co-Bot as the occupied space (s^{Cobot}) and the nominal working temperatures ($T^{Cobot(+/-)}$), as well as the commercial offer of working tools (e.g. gripper, cutter) allow identifying the feasibility tasks for the adoption of an automated system that could replace the involved operators.

When a task or a group of tasks is selected the focus of the methodology is on the design of the infrastructural configuration of the new automated solution. This entails four elements/functional units: *flexible automation* (1), *rigid automation* (2), *packaging* (3), and *control system* (4). The flexible automation (1) regards the Co-Bot, the working tool (e.g. the gripper) and the infrastructure necessary to install the robot and the PLC and to power/feed it properly (i.e. electricity and pressurized-air for the tool). The rigid automation (2) involves conveyors and buffering areas/devices to hold Work In Process and handling tools. The packaging (3), classified into primary, secondary and tertiary package, refers to the handling and container solutions moved and picked by the Co-Bot, or supporting the production tasks. As example, a primary package is a plastic bowl containing a single meal, a secondary package (i.e. a carton or plastic crate) contains many primary packages, and a tertiary package (i.e. a pallet or a roll-container) holds a production lot for storage or transportation purposes. The control system (4) includes all the devices necessary to track the product (e.g. label, barcode, RFID) or to control the process (e.g. optical or force sensors). Together these elements establish the investment (I) required by the project.

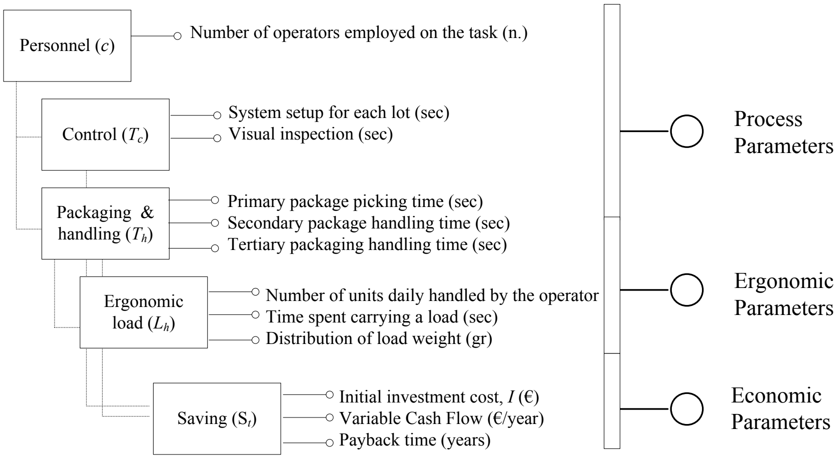

Fig. 1. Hierarchy of performance parameters to be tracked and quantified.

The design phase of the automated layout begins two parallel assessments devoted to the as-is and to-be process respectively. The as-is assessment concentrates on monitoring and tracking the manual tasks with the purpose to quantify the time spent by the operators in those activities. Fig. 1 exemplifies the set of information and design parameters. Each parameter is classified into an area of performance (i.e. process, ergonomic and economic indicators).

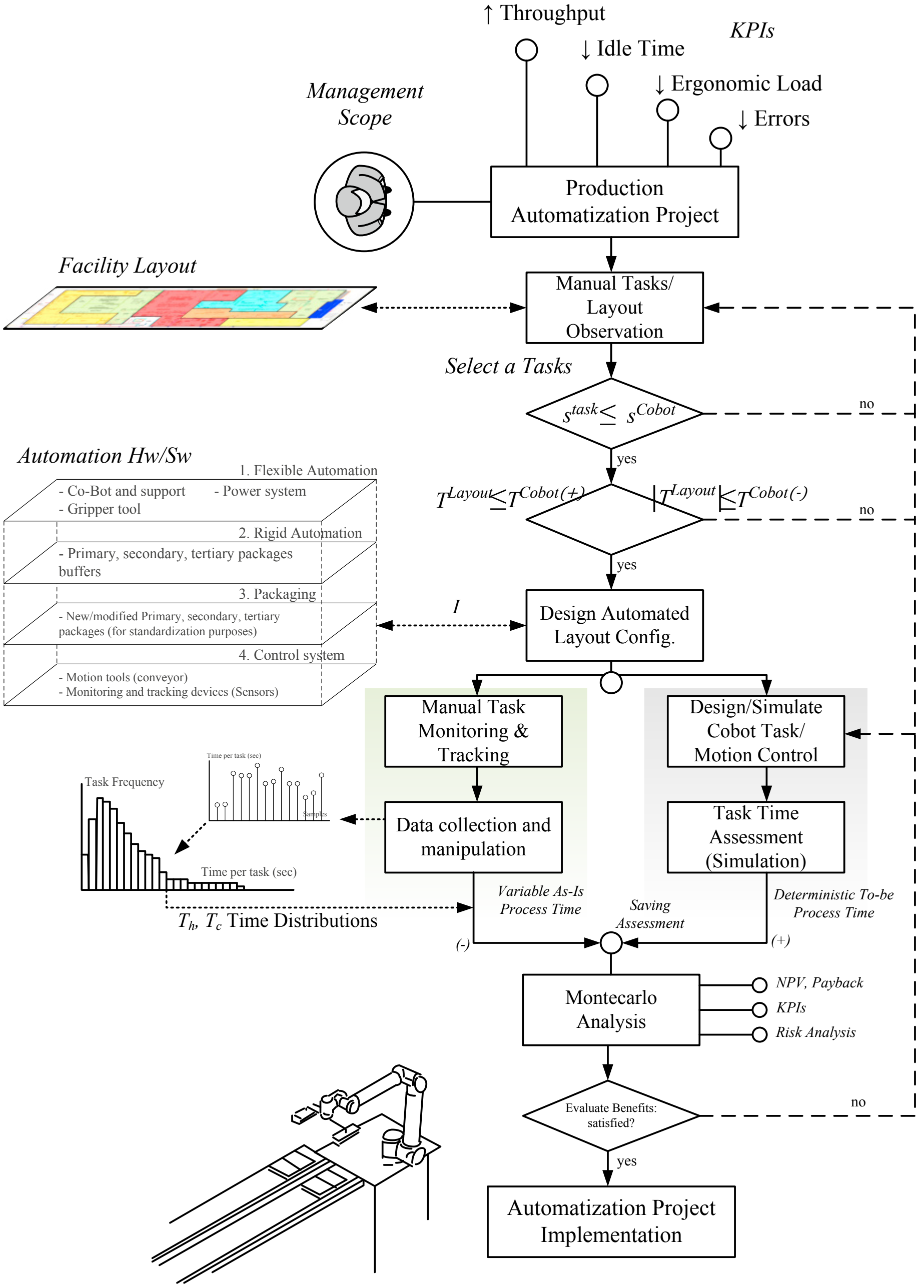

Fig. 2. Methodology for feasibility analysis of automatization projects.

Some of these activities could be replaced by the Co-Bot in the automated layout (e.g. primary package pick-and-placing and secondary package handling), while others will remain manual (e.g. tertiary package handling, inspection, setup). The comparison between the working time between the as-is and the to-be layout results in the calculation of the savings associated to the automation. For the to-be scenario, the deterministic Co-Bot working time can be estimated ex-ante through simulation (or a digital twin), once that the motion/working control script (i.e. control software) has been developed. Conversely, manual activities are typically variable and the related times need to be calculated after extensive observation and monitoring campaigns.

The monitoring campaign results in the collection of task samples and in the elaboration of task-time frequency analyses for all the observed activities (e.g. t^{α}_{pick}, t^{β}_{pick}, t^{γ}_{pick}, t^{β}_{lab}). In the design of an automated pick-and-place system, these distributions of working time can be clusterized into two main contributions:

- T_c, which cumulates the time spent by the operator on supervising the line (i.e. setup, travelling around the line, inspection and problems solving);
- T_h, which cumulates the time spent by the operator for products/packages handling.

The value of T_h is deeply affected by the adoption of a Co-Bot since it drastically reduces the operator handling time. The value, expressed in term of (sec/lot) can be quantified as follows:

$$T_h = t^{\alpha}_{pick} \cdot l^{\alpha} + \left(t^{\beta}_{pick} + t^{\beta}_{lab} + t^{\beta}_{depot}\right) \cdot \left\lceil \frac{l^{\alpha}}{v^{\alpha,\beta}} \right\rceil + t^{\gamma}_{pick} \cdot \left\lceil \frac{l^{\alpha}}{v^{\alpha,\beta}} \cdot \frac{1}{v^{\beta,\gamma}} \right\rceil \tag{1}$$

The value of T_c includes all the activities associated to the supervision of the production line as the travelling from other control points on the plant layout to the end-of-line, the packing line setup activities, as well as the line diagnostic and the resolution of problems and bottle necks. This can be quantified as follows per production lot (sec/lot):

$$T_c = t^{idle} \cdot \left\lceil \frac{l^{\alpha}}{v^{\alpha,\beta}} \right\rceil + t^{trav} + t^{setup} \tag{2}$$

Other two important parameters are the number of lots per day l and the meals per lot l^{α}, which both depend on the demand profiles. Even l and l^{α} can be tracked over time and two discrete probability density functions (PDFs) built accordingly. The comparison between the value of T_h and T_c assessed in the as-is and to-be scenarios can be used to calculate the economic saving S_t as the annual cash flow of the investment in automation. To this purpose, only differential contributions have to be accounted for, assuming that, for example, idle time and setup time will remain the same in both configurations, while the crate labelling task will be performed by the Co-Bot. In the case of a pick-and-place automated system based on a collaborative Co-Bot, the annual economic (€/year) saving can be quantified as follows:

$$S_t = \left(\left(t^{idle} + t^{\alpha}_{pick} \right) \cdot l^{\alpha} + \left(t^{\beta}_{pick} + t^{\beta}_{depot} \right) \cdot \left\lceil \frac{l^{\alpha}}{v^{\alpha,\beta}} \right\rceil - t^{trav} \right) \cdot l \cdot d \cdot c - c^{maint} \tag{3}$$

Where values of the parameters t^{idle}, t^{α}_{pick}, t^{β}_{pick}, t^{β}_{depot}, t^{trav}, l^{α} and l will follow the related PDFs calculated along the monitoring campaign, and c^{maint} is the expected annual cost of the maintenance service.

While Eq. (3) evaluates the return on investment of the automatization project, the introduction of the Co-Bot could also provide significant savings of the ergonomic load for the operators. A draft (and improvable) metric of the ergonomic load is the ratio between the handling time of the operator and the total available time. According to the given notation, such metric can be calculated as follows:

$$L^{Erg} = \frac{T_h}{T_c + T_h} \tag{4}$$

Given the implicit variability of the manual activities and tasks, the determination of the performance of the automated configuration is built through a well-known statistical approach, i.e. Monte Carlo analysis. In this analysis, the value of economic and ergonomic performance are quantified per each iteration of a simulation to support risk analysis on the Net Present Value (NPV), the payback and other returns from the automatization of the production process.

The following section provides details of an application of this methodology for the feasibility analysis of the adoption of a Co-Bot into the packing line of a food catering facility.

3. Case Study

This section presents the feasibility study for the adoption of a Co-Bot to replace the manual activities of the operators at the packing end-of-line of a catering production system. The layout of the production facility is proposed in Fig. 3. The preliminary observation of the production phase and of the facility departments (i.e. raw material storage, raw preparation, cooking, packing), identified the packing operations as the most promising manual activities to be automated.

As the Ce.Ki. produces thousands of meals each day in a typical convergent production system (i.e. job shop), the packing line behaves as a process bottleneck. At the end of an automatic packing line, some operators wait the incoming meals sealed in primary packages, pick-and-place them into a plastic crate (i.e. a box with $v^{\alpha,\beta} = 24$) and then, put stacks of crates onto a roll-container for shipping or storage purposes. The scopes of the production managers are to replace poor-added value activities with automation in order to:

- Reduce the ergonomic load of the operator;
- Reduce the labor idle time;
- Improve the throughput of the bottleneck.

Fig. 3 reports the output from the design of the automated layout configuration, with a focus on the auxiliary pneumatic circuit for the pressurized air required by the Co-Bot's gripper. The new configuration also requires a steel support for the empty crates and a trays-structure to hold and move roll-containers by gravity.

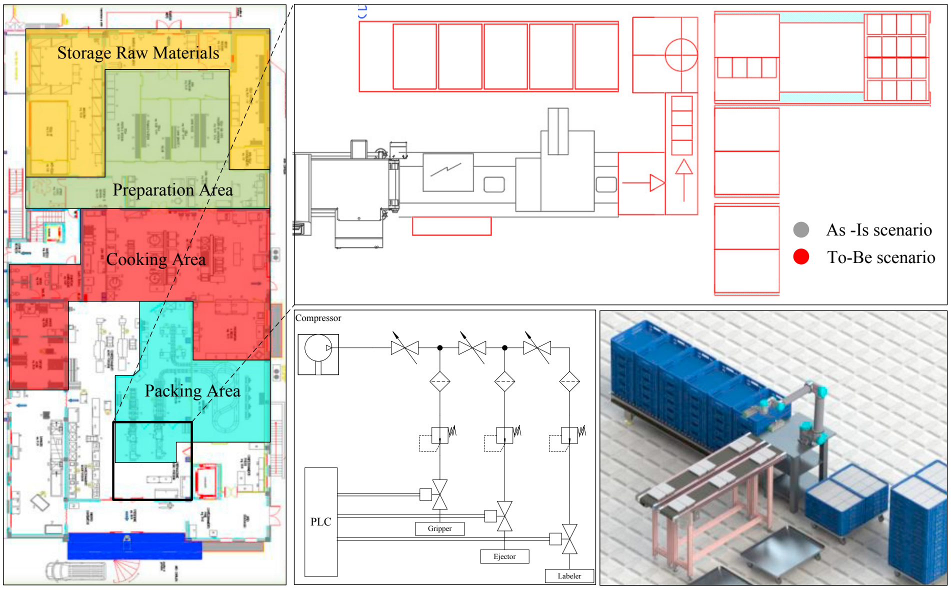

Fig. 3. Facility layout: new automated configuration, the new pneumatic circuit, and views: as-is vs. to-be

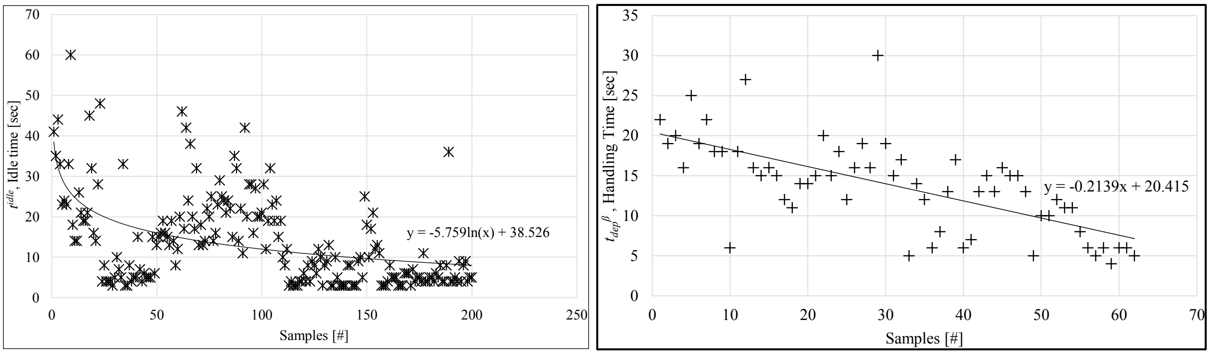

Fig. 4. Results from the monitoring campaign on the manual tasks: t^{idle} and t^{β}_{depot}.

The methodology follows two different pathways for the assessment of the as-is and to-be configurations. The assessment of the as-is configuration is carried out through an extended monitoring campaign (see Fig. 4) on the manual activities, which results in the identification the PDFs for the variables t^{idle}, t^{α}_{pick}, t^{β}_{pick}, t^{β}_{depot}, t^{trav}, l^{α} and l.

On the other hand, a digital twin of the Co-Bot is implemented to aid the design of the motion control script, as well as for the estimation of the deterministic picking times t^{α}_{pick}, t^{β}_{pick} in the to-be configuration. The pseudocode of the control script is proposed in Fig. 5.

```
Input :
Set $N_r$ = number of levels of the roll container
Set $N_c$ = number of plastic boxes for each level of the roll container
Set $\delta_y$ = distance between the center of mass of two pastic boxes on the
same level
Set $\delta_z$ = vertical distance between the center of mass of two pastic boxes
on different levels
Set $p$ = number of levels of products in a plastic box
Set $m$ = number of product in the x direction of a plastic box
Set $m$ = number of product in the y direction of a plastic box
$(x, y, z)$ = tool center point of the cobot
$(X_p, Y_p, Z_p)$ = picking point of a plastic box
$(X_l, Y_l, Z_l)$ = placing point of a plastic box
$(X_r, Y_r, Z_r)$ = picking point of a product
$(X_f, Y_f, Z_f)$ = placing point of a product
Output: R list of predecessors for each task

Set $\epsilon = N_c$
for $\gamma \leftarrow 1$ to $N_r$ do
    if $\epsilon == 0$ then
        Set $\epsilon == N_c$
    end
    for $\beta \leftarrow 0$ to 1 do
        Set $x = X_p$
        Set $y = Y_p + \beta\delta_y$
        Set $z = Z_p\epsilon$
        Pick an empty plastic box
        Set $x = X_l$
        Set $y = Y_l - \beta\delta_y$
        Set $z = Z_l + (\gamma - 1)\delta_z$
    end
    for $i \leftarrow 1$ to $p$ do
        for $j \leftarrow 1$ to $m$ do
            for $k \leftarrow 1$ to $n$ do
                $x = X_r$
                $y = Y_r$
                $z = Z_r$
                Pick a product
                $x = X_f(k)$
                $y = Y_f(j) - \beta\delta_y$
                $z = Z_r(i) + \beta\delta_y$
            end
        end
    end
end
```

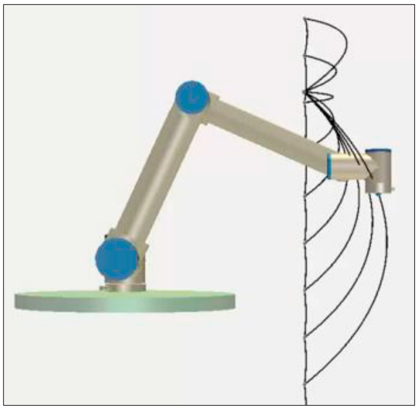

Fig. 5. Pseudocode of the script for the Co-Bot pick-and-place activity and motion simulation of the digital twin.

The methodology supports the analysis of the economic and ergonomic return from the investment (I). About 80% of the initial I is for the purchase and installation of the Co-Bot technology, while the remaining is devoted to re-layout and infrastructural works. Given the uncertain nature of most of parameters observed in the as-is configuration, the evaluation of the savings (both economic and ergonomic) is not deterministic and is carried out through the adoption of a Monte Carlo analysis. Fig. 6 reports the results from a Monte Carlo simulation conducted on the base of 30 iterations, expressed in term of NPV (and related payback) and cumulated ergonomic load saving (ΔL^{Erg}).

The analysis showcases how the payback of the production automatization project (i.e. less than 2 year with a probability of 70%, and less than 2 year and half with a probability of 85%) is significantly affected by the size of the production lot and the number of lots processed per day. Conversely, the lot size poorly influences the benefits in term of reduction of the ergonomic load for the operators.

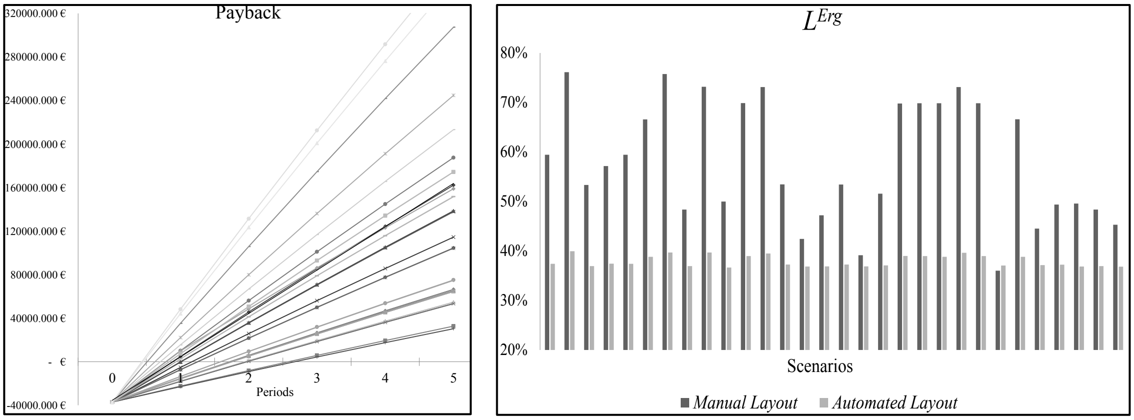

Fig. 6. Automatization performance/savings resulting from a Monte Carlo simulation: NPV and ergonomic load.

4. Conclusion

This paper explores the application of a Co-Bot technology in the food catering industry. The proposed methodology identifies the step of analysis for the design and assessment of automated layout configuration able to replace manual and poor-added value tasks. The illustrated steps lead the decision-makers through the identification of the most promising task to be automatized, the design of functional components of the new layout, the development of the motion script to control the Co-Bot, the monitoring campaign on the manual task to be replaced, and the simulation analysis for the statistical assessment of the economic and ergonomic performance of the automated layout. A feasibility study showcases how to gain benefit from this methodology and provides a practical learning case for production managers and practitioners in the era of production automatization and industry 4.0.

References

[1] A. Fusi, R. Guidetti, and A. Azapagic, “Evaluation of environmental impacts in the catering sector: the case of pasta”, J. Clean. Prod., vol. 132, pp. 146–160, 2015.

[2] L. Benvenuti, A. De Santis, F. Santesarti, and L. Tocca, “An optimal plan for food consumption with minimal environmental impact: the case of school lunch menus”, J. Clean. Prod., vol. 129, pp. 1–10, 2016.

[3] T. Van Kampen and D. P. Van Donk, “Coping with product variety in the food processing industry: the effect of form postponement”, Int. J. Prod. Res., vol. 7543, no. May 2015, pp. 1–15, 2013.

[4] E. Betoret, N. Betoret, D. Vidal, and P. Fito, “Functional foods development: Trends and technologies”, Trends Food Sci. Technol., vol. 22, no. 9, pp. 498–508, 2011.

[5] European Parliament, Reg. (CE) N. 852/2004 del Parlamento Europeo sull’Igiene dei Prodotti Alimentari. 2004.

[6] A. Tufano, R. Accorsi, A. Gallo, and R. Manzini, “Simulation in food catering industry. A dashboard of performance”, in International Food Operations and Processing Simulation Workshop, 2018, pp. 20–27.

[7] S. Penazzi, R. Accorsi, E. Ferrari, R. Manzini, and S. Dunstall, “On the design and control of food job-shop processing systems. A simulation analysis in catering industry”, Int. J. Logist. Manag., vol. 28, no. 3, pp. 782–797, 2017.

[8] P. Amorim and B. Almada-Lobo, “The impact of food perishability issues in the vehicle routing problem”, Comput. Ind. Eng., vol. 67, pp. 223–233, 2014.

[9] A. Tufano, R. Accorsi, F. Garbellini, and R. Manzini, “Plant design and control in food service industry. A multi-disciplinary decision-support system”, Comput. Ind., vol. 103, pp. 72–85, 2018.

[10] A. Khalid, P. Kirisci, Z. Ghrairi, K. D. Thoben, and J. Pannek, “A methodology to develop collaborative robotic cyber physical systems for production environments”, Logist. Res., vol. 9, no. 1, 2016.

[11] A. Realyvásquez-Vargas, K. Cecilia Arredondo-Soto, J. Luis García-Alcaraz, B. Yail Márquez-Lobato, and J. Cruz-García, “Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company”, Robot. Comput. Integr. Manuf., vol. 57, no. October 2018, pp. 315–328, 2019.

[12] A. M. Djuric, R. J. Urbanic, and J. L. Rickli, “A Framework for Collaborative Robot (CoBot) Integration in Advanced Manufacturing Systems”, SAE Int. J. Mater. Manuf., vol. 9, no. 2, pp. 2016-01–0337, 2016.

[13] M. Fechter, C. Seeber, and S. Chen, “Integrated Process Planning and Resource Allocation for Collaborative Robot Workplace Design”, 51st CIRP Conference on Manufacturing Systems, vol. 72, pp. 39-44, 2018.

[14] S. Keller, R. Hausmann, L. Kressner, and A. Koenig, “An approach of a computerized planning assistant to the system design of collaborative robot installations”, IEEE 21st International Conference on Emerging Technologies and Factory Automation, vol. 2016, 2016.

[15] B. Menges, M. Sarrey, and P. Henaff, “Integration of a collaborative robot in a hard steel industrial environment”, 2018 IEEE 14th International Conference on Automation Science and Engineering (CASE), vol. 2018, pp. 634-637, 2018.