Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 39 (2019) 1428–1437

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

25th International Conference on Production Research Manufacturing Innovation: Cyber Physical Manufacturing
August 9-14, 2019 | Chicago, Illinois (USA)

The Response Latency in Global Production and Logistics: A Trade-off Between Robotization and Globalization of a Chain

David Bogataj*, Daria Battini, Martina Calzavara, and Alessandro Persona

University of Padova, Department of Management and Engineering, Stradella S. Nicola 3, Vicenza, Italy

Abstract

The vision of Industry 4.0 foresees also much lower time delays between activities and feedback control. Among factors which influence delays in supply chains are long distances between activities in a complex global supply chain and the response latency of older workers, in the case that there are no properly developed programs for avoiding this phenomenon. The analysis of a trade-off between these factors is the subject of this article. Mitigating the decreasing functional capacities of the ageing workforce, to keep the old workers' productivity on the higher level while their functional capacities are decreasing, collaborative robots and smart workstations are advised. The second solution is to move a part of production to foreign countries where the demographic structure is in favour of young workers, and human resources are much cheaper. In the article, we are developing a model for a trade-off between two solutions: to invest in collaborative robots or to develop early retirement schemes and to move the production plants abroad. Therefore, the basic trade-off is between robotisation, keeping short distances between activity cells in a supply chain, and transportation costs which include also additional costs of delays in a system. The model is based on the skeleton of the extended MRP theory of Grubbström and Bogataj and evaluated by the NPV and, as a novelty, also by the actuarial present value APV in the criterion function. Extended MRP enables to extend the model of multi-echelon systems which is presented by the same authors in the *International Journal of Production Economics*, under the title: *The ageing workforce challenge: investments in collaborative robots or contribution to pension schemes, from the multi-echelon perspective to global supply chains.* The article explains why it is important to link the annuities for repaying the investment in robots to the flow of funds for workers' salaries when weighing between early retirement and investment in collaborative robots. The model is applied to a real industrial case of the production of pumps and can be easily implemented also in other international supply chains where the differences in the demographic structure, salaries and automatization between countries are substantial and the eligibility of transport costs is questionable.

Keywords: Time delays, human resources, robotization, response latency, transportation costs, Actuarial Present Value, investments

1. Introduction

Working populations in the European Member States are ageing, and cities are shrinking. Age related expenditures on health care, long-term care and pensions in national social systems claim increasing share of GDP [1]. Pension spending in Luxembourg is projected to rise from 9.0% of GDP in 2016 to 17.9% in 2070 Significant growth in pension spending is projected for Belgium, Czech Republic, Germany, Cyprus, Luxembourg, Malta and Slovenia. Spending on health care is projected to grow in all EU Member States and spending on long-term care is projected to almost double in many countries. To

* Corresponding author, e-mail: david.bogataj@unipd.it; tel.: +38641670572

2351-9789
10.1016/j.promfg.2020.01.309

stay competitive supply chain managers will need to understand long term care dynamics of age-related expenditures (contributions to national social systems for pensions, health care and long term care) and required growth in productivity of their European operations. Therefore, the age management and reforms in which retirement age is increasing, are becoming key areas of activities by which human resources are managed within organizations and social systems with an explicit focus on ageing via public policy or collective bargaining [2]. Europe 2020 strategy states as employment target: "75% of people aged 20–64 to be in work". Challenges are highlighted in the recently published EUROFUND study [3]. The retirement age in public pension schemes will reach 70 years by 2060, in many EU member states. Many industrial and logistics workers will not be able to work to the increased retirement age. Their Unions require better workplace ergonomics or the possibility of early retirement. The expected healthy life years at birth is 17 years shorter than the overall life expectancy for men and 22 years for women. In this time windows, many workers need to receive pensions. The challenge of an ageing workforce brings various aspects that need to be addressed to achieve sustainability and competitiveness of supply chains. Regarding Industry 4.0, many authors [4] recently concluded that older adults require a longer time to solve a computational problem and had decreased accuracy by ageing, having problems when the task is more complex. Namely, because of rapid advances in modern technologies, employees should control more and more complex production and logistic processes in which they have to control multiple displays. They have to operate simultaneously many input devices. In studies of many researchers, about tasks that required more complex executive functioning, the conclusions are that such tasks had greater age discrepancy in performance variability, with more frequent and larger performance variabilities in the older participants. According recent study of workers in assembly line, experienced older workers as members of a team can improve the productivity [5] when including in assembly line. The details about ageing workforce management in manufacturing systems are described in Calzavara et al. [6]. The main reason for the decline in the productivity of older workers is an increase in absence from work due to ill health. It causes lower capacities in production and perturbations in timing as analyzed already in [7,8,9], on the bases of Grubbström's MRP Theory, described in an overview [10] and updated in [11]. According to [12], musculoskeletal disorders are steadily increasing by the ageing of workers performing assembly jobs which frequently involve highly repetitive, short-cycle operations in assembly processes. By increasing the official retirement age, the number of workers qualifying for disability pensions on the grounds of musculoskeletal disorders, like spinal disease and strain injuries is increasing [13]. Aittomaki et al. addressed the association between advancing age and poor performance in physically demanding work [14]. A correlation between age and productivity depends on the workplace and physical characteristics of workers because of their incline to different kind of musculoskeletal disorders [12]. According to the analysis of Aiyar et al. productivity at 22% of workplaces in EU is increasing with the ageing of workers (managers and highly educated and skilled professionals), at some workplaces (around 23%) the productivity is age-neutral, while for employed in machine operators and assemblers the productivity is decreasing by ageing [15]. This population is subject of consideration in the paper. There are many solutions to solve the problem when a worker falls under the threshold of abilities to continue his/her work at his/her workplace properly. One of the solutions is to relocate him/her on the less demanding workplace; second is to give him better supporting environment like collaborative robots or enable him to work for shorter working time per day, or to allow him to retire.

In the paper, we show how to measure the influence of ageing on the perturbation of NPV in production and logistics, as results of the simultaneous perturbations of the timing. These perturbations can be better evaluated simultaneously through the Input/Output analysis, Laplace transforms and the NPV expression which enables us to forecast and control the physical and financial flows simultaneously. In each activity cell of a supply chain, the functional decline of workers is different. For each workplace exist the optimal retirement age. Retirement age at the workplace can increase in the case of investment in workplace ergonomics. The functional decline of workers influence parameters of pension schemes, health, and long-term care insurance schemes. In short, if most people continue to retire at around 60 years of age, the European labour force will shrink by around three million per year over the period 2020 to 2035 as reported by EU-OSHA [3]. There is a need for a new and more comprehensive policy design to counter the shortage of workers in the future, particularly to keep workers in employment for longer. This cannot be done by cutting pension entitlements to force people to work for longer, but must be thought of as a systemic change, "thinking about work from a life-course perspective" the improvements of poor workplace ergonomics which influence productivity is the best approach to solve these problems [6, 16, 17]. According to one of the four principles of Industry 4.0, there is a need to support humans by innovative new ergonomics-oriented equipment and collaborative robots. Consequently, currently, there is a growing demand for applications with arm-based robots [18]. Robots will become a safe help to reduce fatigue and cognitive stress during human work, without substituting expert workers. To invest in such systems or to delocalize the production system in East of EU is the question to which the model will answer. While the paper [19], based on the MRP Theory, did not consider transportation matrix with transportation delays (the all multi-echelon production was considered under one roof), here we shall pay particular attention to the transportation costs and transportation delays as discussed and implemented by Battini et al. [20] on the bases of previously introduced perturbed transportation matrices [21].

The structure of the paper is the following: The chapter 2 is divided in explanation why the Grubström's MRP model is the best for studying the impact of latency of human resources on the perturbations in the total supply chains, and explain the options which are available to reduce the impact on these consequences *(2.1),* while the second subchapter is based on the extension of MRP model by introduction of *transportation delay matrix* and *transportation direct costs matrix*, recently developed by Bogataj et al, as stepwise presented in [23],[25] and [26]. The development of this theory (without analysis of perturbations) is broadly described in [11]. In the chapter 3 the economic consequences are described. There is explained why the net present value of the cost of goods sold should contain the actuarial present value and not only the net present value of salaries, and why the investments in cobots should be modelled as suggested here, which was often question of scientists when discussing this approach. At the end, the chapter 4 is presenting a numerical example, which was given as a typical case when a company or the network of producers decide to find a cheaper workforce in a foreign country, but transportation costs become substantial in such cases. As the model does not include some other important factors, like environmental consequences and environmental taxes, also obsolesce and other reasons for decision making on a finite horizon are not considered here, therefore the list of suggestions for further research is proposed at the end of this paper.

2. The basic model

2.1. Human resources in the extension of the Grubbström's MRP Theory

In this paper the model published in [19] will be extended in modelling global supply chains, and the actuarial present value will be introduced in total evaluation of the NPV of the net profit. The article [19] is based on the skeleton of the MRP theory of Grubbström [22],[10] and the income evaluated by the NPV in the criterion function. The introduction of the transportation matrices (the perturbed transportation lead time matrix and the perturbed transportation costs matrix) in the model enables to extend the model of multi-echelon systems presented by Bogataj et al. [19] to a global supply chains. Let us structure the costs of labour to the costs of current salaries $c_{L,i}$ in each workplace i , contributions to a pension scheme $\alpha_{R,i}c_{L,i}$ where $\alpha_{R,i}$ is a share of salary which goes to the pension fund, and costs of investments in collaborative robots and other ergonomic improvements $\alpha_{R,i}c_{L,i}$. We shall consider an option that investments in collaborative robots increase the labour cost from $c_{L,i}$ to $c_{L,i}(1+\alpha_{E,i})$, where $\alpha_{E,i}\cdot c_{L,i}$ are factored into the program of investments in ergonomics and $\alpha_{R,i}\cdot c_{L,i}$ are factored into the application of earlier retirement. There are two options for decisions: (a) the ergonomics could also be improved enabling seniors to work longer or (b) early retirement schemes are introduced and some activities are allocated in foreign country, where human resources are less expensive but perturbations on the roads and border crossings could add additional uncertainties [8,24]). Any of these decisions could influence the quality and quantity of production in the workplace and also affect the lead time in a supply chain. The benefit to the total supply chain could be evaluated through using the Net Present Value (NPV) approach only because investments and activities have different dynamics on the time horizon of the production and distribution in the total supply chain. The analysis in the paper is based on *MRP theory,* as found in the papers of Grubbström [10, 22], being extended to the global supply chain [23,25,26] in which the location of activity cells is also considered [23,27] including regional characteristics, such as the cost of labour and ageing of the European population. According to the basic MRP theory [10,22] shortly described below, the *j*-th process is run on activity level (in node *j)* having intensity P_j , the volume of required inputs of item *i* is $h_{ij}P_j$ per time unit. The total of all inputs may then be collected into the column vector **HP**. The net production is determined as (**I** - **H**)**P**. In general, **P** is a time-varying vector-valued function. In MRP systems, *lead times* could be easily studied simultaneously in a total supply chain if using the Laplace Transforms methodology.

2.2. Delays in transportation and the generalised transportation - production matrix

If $P_j(t)$ is the rate of items *j,* planned to be completed at time *t*, then the number $h_{ij}P_j(t)$ of items *i* need to be available for production or reloading in a time unit which is a lead time τ_j in advance of time *t*, i.e. at the time $(t-\tau_j)$, before starting this production process. Because of the transportation delay, it should be sent from the previous activity cell at a time $(t-\tau_{ij}-\tau_i)$. While the item i is assumed to be located previously at the location i it will be available for activity j at the location j before the activity $P_j(t)$ starts, and it will need a certain time τ_{ij} to arrive there. For our needs, we consider an *assembly* system of water pumps. This process can be perturbed in nodes by reducing the functional capacities of ageing workers or on roads because of customs duties on borders, road works, accidents and other reasons, which could influence cascaded risk. The input requirements are given as transforms in the perturbed *generalised transportation- production-input matrix*, which is denoted $\breve{\mathbf{H}}'(s)$. $\breve{\mathbf{H}}_0'(s)$ is perturbed transportation lead time matrix.

$$\breve{\mathbf{H}}_0'(s)=\begin{bmatrix} 0 & 0 & \cdots & 0 \\ h_{21}e^{s\tau_{21}(1+\delta_{21})} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ h_{n1}e^{s\tau_{n1}(1+\delta_{n1})} & h_{n2}e^{s\tau_{n2}(1+\delta_{n2})} & \cdots & 0 \end{bmatrix} \tag{1a}$$

Thus, the requirements for the production plan $\tilde{\mathbf{P}}(s)$ written as $\breve{\mathbf{H}}'(s)\tilde{\mathbf{P}}(s)$ are specified in the frequency domain where the net production $\tilde{\mathbf{x}}(s)$ will conveniently be written as follows:

$$\breve{\mathbf{H}}'(s)=\breve{\mathbf{H}}_0'(s)\cdot\begin{bmatrix} e^{s\tau_1(1+\delta_{\tau 1})} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & e^{s\tau_n(1+\delta_{\tau n})} \end{bmatrix};\tilde{\mathbf{x}}(s)=(\mathbf{I}-\breve{\mathbf{H}}'(s))\tilde{\mathbf{P}}(s). \tag{1b}$$

For *cyclical processes*, which repeat themselves in constant time intervals Γ_j, $j = 1, 2, \ldots, n$, the plan $\tilde{\mathbf{P}}(s)$ is written [10,25,26] and here extended because of ageing to the perturbed

$$\tilde{\mathbf{P}}(s) = \tilde{\mathbf{t}}'(s)\tilde{\Gamma}'(s)\hat{\mathbf{P}} = diag(e^{\frac{-st_1(1+\sigma_1)}{1-e^{-s(\Gamma_1+\Delta\Gamma_1)}}}, \ldots, e^{\frac{-st_n(1+\sigma_n)}{1-e^{-s(\Gamma_n+\Delta\Gamma_n)}}}) \cdot \hat{\mathbf{P}}. \tag{2}$$

Here $\tilde{\mathbf{t}}'(s)\tilde{\mathbf{\Gamma}}'(s)$ is the product of perturbed matrices of starting moment of activities $\tilde{\mathbf{t}}(s)$ and total cycle $\tilde{\mathbf{\Gamma}}'(s)$, $\hat{\mathbf{P}}$ is a vector of constants: for instance, batch sizes to be produced in each process during one of the periods $\Gamma'_j = \Gamma_j + \Delta\Gamma_j$, $j = 1, 2, \ldots, n$. Furthermore, in the above equation (2), $t_j(1+\sigma_j)$, $j = 1, 2, \ldots, n$, are the points in time when the first of each respective cycle starts being perturbed for $t_j\sigma_j$ because of declining functional capacities of workers at *j*-th nodes. Let us use the approximation for perturbed expression describing $\tilde{\mathbf{P}}(s) = \tilde{\mathbf{t}}(s)'\tilde{\mathbf{T}}(s)'\hat{\mathbf{P}}$

$$\tilde{\mathbf{P}}(s) = \begin{bmatrix} \dfrac{e^{-st_1(1+\sigma_1)}\hat{P}_1}{1-e^{-s(\Gamma_1+\Delta\Gamma_1)}} & \cdots & \dfrac{e^{-st_n(1+\sigma_n)}\hat{P}_n}{1-e^{-s(\Gamma_n+\Delta\Gamma_n)}} \end{bmatrix}^T \doteq \frac{1}{s}\begin{bmatrix} \dfrac{e^{-st_1(1+\sigma_1)}\hat{P}_1}{\Gamma_1+\Delta\Gamma_1} & \cdots & \dfrac{e^{-st_n(1+\sigma_n)}\hat{P}_n}{\Gamma_n+\Delta\Gamma_n} \end{bmatrix}^T. \tag{3}$$

Let us collect the economic values of items into a perturbed price vector **p,** which is a row vector, as follows:

$$\mathbf{p} = \mathbf{p}^1 + \Delta\mathbf{p} = \left[p_1^1(1+\delta_1), p_2^1(1+\delta_2), \ldots, p_n^1(1+\delta_n)\right], \tag{4}$$

where δ_i is the relative reduction of prices of the item i $(\delta_i \le 0)$, because the worker in the production unit i is no longer able to assure the best quality of products, due to his advanced age or because we have replaced this worker with a new one without needed specific skills on distant location. By investments in better ergonomic conditions in workplaces, the reduction of negative δ_i could be achieved. The choice between better products with higher price and lower transportation costs and reduced lead-times on the one hand and not to invest in improvements of ergonomic conditions, on the other hand, and retired earlier, can be achieved based on the NPV evaluation. According to the *Net Present Value Theorem*, the NPV of the cash flow is obtained by replacing the complex frequency *s* with the continuous interest rate ρ, for example for NPV of production NPV_{prod}, ordering and fix costs per cycle $\mathrm{NPV}_{\mathrm{ord}}$, and transportation $\mathrm{NPV}_{\mathrm{tr}}$, the total NPV: $\mathrm{NPV}_{\mathrm{tot}}$ for the perturbed system is:

$$\begin{aligned} \mathrm{NPV}_{tot} = \mathrm{NPV}_{prod} + NPV_{ord} + NPV_{tr} = \sum_{i=1}^{n}\Big(p_i\,(1+\delta_i)\Big)\tilde{x}_i(\rho) - \\ -\left\{\frac{\mathbf{K}+\mathbf{E}^T\mathbf{\Pi}}{\rho}\right\}\begin{bmatrix} \dfrac{e^{-(\rho)t_1(1+\sigma_1)}\hat{P}_1}{\Gamma_1+\Delta\Gamma_1} & \cdots & \dfrac{e^{-(\rho)t_n(1+\sigma_n)}\hat{P}_n}{\Gamma_n+\Delta\Gamma_n} \end{bmatrix}^T \end{aligned} \tag{5}$$

In (5) $\mathbf{K}$ is a row vector of the setup costs and other fixed costs of the cycle also costs of annuities for other investments except for investments in the collaborative robots. In (5) $\mathbf{\Pi}$ is a perturbed transportation costs matrix:

$$\mathbf{\Pi} = \begin{bmatrix} 0 & 0 & \cdots & \cdots & 0 \\ h_{2,1}b_{2,1}\tau_{2,1} & 0 & \cdots & \cdots & 0 \\ \vdots & h_{3,2}b_{3,2}\tau_{3,2} & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ h_{n,1}b_{n,1}\tau_{n,1} & \cdots & \cdots & h_{n,n-1}b_{n,n-1}\tau_{n,n-1} & 0 \end{bmatrix} \cdot \boldsymbol{\tau}(\text{perturbed}) \quad , \tag{6}$$

where b_{ij} is the cost of transportation of one unit of the item i one hour on the route from i to j so that the cost of transportation one item all along this route is $b_{ij}\tau_{ij}$. Here also perturbations of τ will be considered and therefore The unperturbed transportation costs matrix is multiplied by matrix $\boldsymbol{\tau}$(perturbed), which depends on location of activities and therefore on transportation of items between them. Considering the long-term profit of a supply chain and its *NPV* we also need to include the direct costs of labour including early retirement premiums and investments in robots into account. The total *NPV* (NPV_{tot}) is reduced for the payments to the labour in individual places of activities with production or distribution intensity P_i, including the part of earnings which goes to the occupational pension funds, and the amount which goes to the annuity stream of investment in ergonomics to support workers, like investments in robots and other new equipment which improve ergonomics of workers. Here the investments to the robots will be considered as a part of earnings (tied to work) and not fix costs.

3. Economic consequences

3.1. Present value of the expected profit on the infinite horizon

The early retirement age, as determined in an occupational pension scheme, could be achieved by increasing the contributions from gross earnings $c_{L,i}$ to the extra-occupational pension schemes $\alpha_{R,i}c_{L,i}$ for workers at the activity cell i. The trade-off between additional pension and investments in ergonomics could lead to the decision that a part of income goes to the annuities for robots and other investments in ergonomics $\alpha_{E,i}c_{L,i}$, calculated relative to the costs of labour. If early retirement age would be a decision, a part of production should go in a foreign country, which means additional costs of transportation and exposure to higher risks. Thus, if the labour cost would increase from $c_{L,i}(1+\alpha_{R,i})$ to $c_{L,i}(1+\alpha_{E,i})$, where $\alpha_{E,i}c_{L,i}$ is factored into the program of collaborative robots and other investments into ergonomics, the ergonomics could be improved enabling seniors to work longer, but $\alpha_{R,i}c_{L,i}$ may lower the retirement age of a worker at the workplace i. The costs of work which include collaborative robots in the total *NPV* could be written as $c_{L,i}(1+\alpha_{E,i})L_iP_i$. Here L_i is the number of employed at i. Also, $c_{L,i}\alpha_{E,i}$ includes maintenances and depreciation costs per cycle, where $c_{L,i}(1+\alpha_{R,i})$ is the cost of one unit of work, which also includes the part of gross earnings $\alpha_{R,i}$ that is sent to the occupational pension fund. These costs are connected with costs of labour in distant country and transportation costs to that locations, to be able to retire earlier — the amount of annuity for investments into the ergonomic improvements, including investments in robots. We need to write the *NPV* of the cost of labour and annuities for improvement of the ergonomic environment, keeping production at home with negligible transportation costs (a), and early retirement and export the product in the foreign country with substantial additional transportation costs (b). Therefore, the NPV of the profit of total supply chain in case of local production in Italy (a) and case of extension of the supply chain to a foreign country (b) is the following

$$\mathrm{NPV}_{profit}(\mathrm{a}) = \mathrm{NPV}_{prod} - NPV(E) - NPV_{ord} = \sum_{i=1}^{n}\Big(p_i\,(1+\delta_i)\Big)\tilde{x}_i(\rho) - \frac{1}{\rho}\sum_{i=1}^{n} c_{L,i}(1+\alpha_{E,i})L_i\,\frac{e^{-(\rho)t_i(1+\sigma_i)}\hat{P}_i}{\Gamma_i+\Delta\Gamma_i}$$
$$-\left\{\frac{\mathbf{K}}{\rho}\right\}\left[\frac{e^{-(\rho)t_1(1+\sigma_1)}\hat{P}_1}{\Gamma_1+\Delta\Gamma_1}\quad\cdots\quad\frac{e^{-(\rho)t_n(1+\sigma_n)}\hat{P}_n}{\Gamma_n+\Delta\Gamma_n}\right]^T \tag{7}$$

$$\mathrm{NPV}_{profit}(\mathrm{b}) = \mathrm{NPV}_{prod} - NPV(R) - NPV_{ord} - NPV_{tr} = \sum_{i=1}^{n}\Big(p_i\,(1+\delta_i)\Big)\tilde{x}_i(\rho) -$$
$$-\frac{1}{\rho}\sum_{i=1}^{n}\left\{\Big[c_{L,i}(1+\alpha_{R,i})L_i + c'_{L,i}L'_i\Big]\frac{e^{-(\rho)t_i(1+\sigma_i)}\hat{P}_i}{\Gamma_i+\Delta\Gamma_i}\right\} - \left\{\frac{\mathbf{K}+\mathbf{E}^T\mathbf{\Pi}}{\rho}\right\}\left[\frac{e^{-(\rho)t_1(1+\sigma_1)}\hat{P}_1}{\Gamma_1+\Delta\Gamma_1}\quad\cdots\quad\frac{e^{-(\rho)t_n(1+\sigma_n)}\hat{P}_n}{\Gamma_n+\Delta\Gamma_n}\right]^T. \tag{8}$$

The owners of a supply chain will choose the chain for which:

$$\max\left\{\mathrm{NPV}_{profit}(\mathrm{a}), \mathrm{NPV}_{profit}(\mathrm{b})\right\} \tag{9}$$

is achieved. In the line with the Industrial Agenda of the World Economic Forum in Davos, the paper presents a common assessment of end-to-end supply chain.

3.2. The actuarial present value APV

According to the equation (9), the owners and managers of a supply chain will jointly find the maximum of NPV which also include the actuarial present value APV. The early retirement age x+n which is h years earlier that the retirement age of public pension scheme, could decrease by increasing contributions from gross earnings of workers on $c_{L,i,j}\cdot\alpha_{i,j}(x,n,h)$. The contribution rate should be

$$\alpha(x,n,h) = \frac{{}_h p_x\cdot\upsilon^h\cdot(1+\gamma_2)\cdot\sum_{k=0}^{n-1}{}_k p_{x+h}\cdot\upsilon^k}{(1-\gamma_1)\cdot\sum_{k=0}^{h-1}{}_k p_x\cdot\upsilon^k}\cdot\ rr \tag{10}$$

The actuarial present value should be

$$APV = c_{L,i,j}\cdot\alpha_{i,j}(x,n,h)\cdot\ddot{a}_{x:\overline{h}|} = c_{L,i,j}\cdot\alpha_{i,j}(x,n,h)\cdot\sum_{k=0}^{h-1}{}_k p_x\cdot\upsilon^k \tag{11}$$

where the notation is given in Table 1:

Table 1: The actuarial present value APV of the early retirement

$rr = erp / c_{L,i,j}$	The replacement ratio rr = ratio between the early retirement pension erp and the gross salary without contribution to pension schemes	${}_n p_x$	the probability that person x years old will survive n years
γ_2	percentage of the administrative fee charged for each payment of the pension benefit	o	Technical yearly interest rate of early retirement occupational pension schemes
γ_1	percentage of the administrative fee chargeed at each payment of pension contributions	$\upsilon = 1/(1+o)$	discounting factor where o is the annual interest rate.

4. Numerical example

The program of early retirement is acceptable for a supply chain if $\alpha_{i,j}(x,n,h,rr)$ in the evaluation of ΔNPV_{total} as presented in equation (7)-(8) could be higher or equal to $\alpha_{R,i,j}(x,n,h,rr)$, determined in table 2 so, that the actuarial present value of all contributions in the pension schemes are lower than ΔNPV_{total} .

Table 2. The actuarial evaluation of the contribution rate for early retirement

Age at first employment	Working period	$\ddot{a}_{x,\overline{n}\rceil}$	${}_n p_x$	Retirement age	$\ddot{a}_{x+n,\overline{h}\rceil}$	$\alpha_{R,i,j}(x,n,h,rr)$	
X	N			x+n		$rr=1$	$rr=0.6$
25	40	38.83	0.91	65	4.909	0.115	0.096
25	41	39.73	0.90	66	3.941	0.089	0.054
25	42	40.62	0.89	67	2.969	0.065	0.039
25	43	41.50	0.89	68	1.989	0.042	0.025
25	44	42.38	0.88	69	1.000	0.021	0.012
25	45	43.25	0.87	70	0.000	0.000	0.000

If the costs of the robot are 60,000 euros, while the depreciation rate is 10% and annual maintenance is 3,000 euros, the NPV of costs of the robot is 148,005 euros (see table 3). Let us denote L_C^Y as the yearly labour costs, M_C^Y is the yearly maintenance costs and *VCR* is the price of the robot including installation. We use the notation *dp* for depreciation period which is the same as the repayment period for investment in robots. The total costs associated with the use of robots at a certain workplace are the sum of the depreciation cost, interest cost and maintenance cost. At a discount υ we can calculate α_E at different annuities *(dp):*

$$\alpha_E(dp) = \left[(VCR / \sum_{k=0}^{dp-1} \upsilon^k) + M_C^Y \right] / L_C^Y$$

Table 3: The costs associated with the use of robots

Price of robot	annual maintenance costs	annuity		annuity + maintenance		NPV of investing and using the robots	
VCR	M_C^Y	*dp=5 years*	*dp=10 years*	*dp=5 years*	*dp=10 years*	*dp=5 years*	*dp=10 years*
30,000	1,500	6,599	3,700	**8,099**	**5,200**	131,986	74,003
45,000	2,250	9,899	5,550	**12,149**	**7,800**	197,978	111,004
60,000	3,000	13,199	7,400	**16,199**	**10,400**	263,971	148,005

The numerical example is getting inspiration from an Italian manufacturer of water pumps. The product design and production are all made in Italy, but because of ageing of human resources and a shortage of new workers they have two options: (a) to buy the collaborative robots and extend their retirement age or (b) to retire them earlier, to pay in early retirement schemes and to open a new factory or in Hungary (close to Budapest: 11 hours distance, 0.16 Euros/item) or in Bulgaria (close to Sofia: 17 hours, 0.22 Euros/item). The costs of labour see EUROSTAT http://ec.europa.eu/eurostat.

The costs are given in table 4. The norm-production per activity per item is written on the lines that leave individual activities in fig. 1. The transportation delays are presented by arcs, The raw material is coming from Italy, and in the case of establishing production units in Hungary or Bulgaria, two semi-products would be sent there: the engine pre-assembly units and the Venturi group pre-assembly units. The final product would be transported back (see fig. 1). Environmental restrictions and pollution fees are not considered in the calculations by Eq. (7).

Table 4. The comparison of the costs of labour

County	Hourly [€]	Yearly [€]	Ratio to the Italian salary k_α
Italy	20.00	38,400	1
Hungary	8.30	15,936	0.415
Bulgaria	4.40	8,448	0.22

Table 5. Calculation of the transportation costs at 80 pcs/palette, 33paletts/truck and 1.2 Eur/km

From/to	Distance	Transport/truck cost	pcs/truck	transport/pcs
	km	[€]	[€]	[€]
Vicenza - Budapest	800	960	2640	1,69
Vicenza - Sofia	1300	1560	2640	2,75

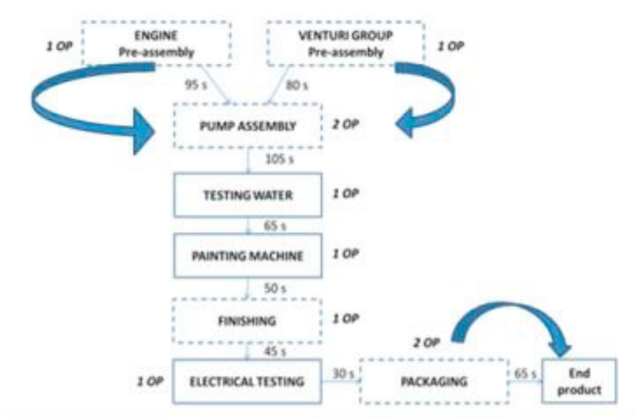

Figure 1. The production graph with process times and a given number of workers.

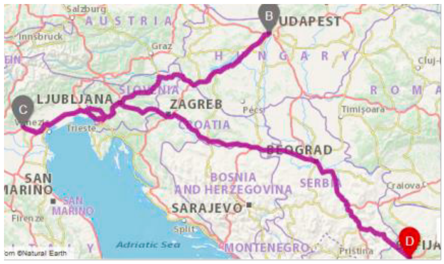

Figure 2. The transportation of parts or semi-products from Vicenza to the East.

Following equations (7) and (8), in case that we decide to remove all perturbations (in timing and quality) caused by ageing, by investing in 8 collaborative robots which cost 60,000 euros each and depreciation period is 10 years, which increase for 20% because of timing and product quality, then in case of allocation of activities in the foreign countries and paying in the occupational pension funds gives the following differences in the present profit:

$$\Delta\mathrm{NPV}_{profit}(\mathrm{b,\ Bud}) = 0.2(\mathrm{NPV}_{prod} - NPV_{ord}) - \frac{1}{\rho}\sum_{i=1}^{n}\left[c_{L,i}(1+\alpha_{R,i}+k_\alpha(Bud))L_i + \sum_{j=i+1}^{n} h_{j,i}b_{j,i}\tau^{Bud}{}_{j,i}\right]\frac{e^{-(\rho)t_i}\hat{P}_i}{\Gamma_i}$$

$$\Delta\mathrm{NPV}_{profit}(\mathrm{b,\ Sof}) = 0.2(\mathrm{NPV}_{prod} - NPV_{ord}) - \frac{1}{\rho}\sum_{i=1}^{n}\left[c_{L,i}(1+\alpha_{R,i}+k_\alpha(Sof))L_i + \sum_{j=i+1}^{n} h_{j,i}b_{j,i}\tau^{Sof}{}_{j,i}\right]\frac{e^{-(\rho)t_i}\hat{P}_i}{\Gamma_i}$$

where i=1 is the final delivery point and has no costs of labour. Here all perturbations described in transportation matrices are influencing ΔNPV. The product price to the final user is assumed to equal to 250 euros per pump. Following the equation (7) we can see that in case of 4% interest rate or lower, the $NPV_{profit}(\mathrm{a})$ is 2.33 times higher in case of the total production in Italy comparing the production in Budapest and 2.45 times higher in Italy comparing the transportations to Sofia and partly produced there.

It is better to keep the production in Italy and to buy the collaborative robots for each human operator involved in each station in Italy, even in the case that investments in production systems in a foreign country would be covered by European structural funds. The new robot will provide the needed flexibility of the interfaces between parts and workstations at the country of origin (Italy). Therefore in such an environment

$$\max\left\{NPV_{profit}(\mathrm{a}), NPV_{profit}(b,Bud), NPV_{profit}(b,Sof)\right\} = NPV_{profit}(\mathrm{a})\cdot\max\left\{1,0.43,0.41\right\} = NPV_{profit}(\mathrm{a})$$

5. Conclusion

In the article is discussed how collaborative robots will become a safe support to reduce fatigue and cognitive stress during human work, especially in the case of older workers. But we should be aware of the fact that the collaborative robot cannot totally substitute the craft workers and other highly experienced industrial workers. To invest in such systems or to delocalize the production system in East of EU is the question to which the proposed model can answer. While the paper [19], based on the MRP Theory, did not consider transportation matrices with transportation delays and transportation perturbed costs (the all multi-echelon production was considered under one roof), here a particular attention has been paid to the transportation costs and transportation delays as discussed and not totally implemented by [20] on the bases of previously introduced perturbed transportation matrices of Bogataj and Bogataj [21]. Here is presented how the introduction of proper age management of human resources could reduce time delays and therefore support mitigating of a supply chain risk when also reallocation of production to other countries is considered and therefore the model of the multi-echelon system [19] should be extended, using the Net Present Value approach in Extended MRP model and additional perturbations should be considered. Therefore the contributions to ergonomics, occupational pension schemes for earlier retirements and LTC schemes should be developed and NPV should be compared with the actuarial present value APV. The numerical example for Italian worker with an average net salary shows that the contributions to all these funds require more than 100% of net salary to achieve sustainable supply chains and an adequate ergonomics, pensions, LTC and health insurance. In the next 40 years, this percentage will rise with the further ageing of the population. Therefore, this value is so high that further research needs to include these contributions to the evaluation of the costs of human resources including investments in smart production cells and collaborative robots. As far as the authors know, this is the first attempt that Extended MRP model is applied to demonstrate the trade-off between investments in collaborative robots or relocation of production in the foreign country. Here is assumed that in the Eastern countries the costs of human resources are lower and structural funds are available for investment in production. To solve the problems of declining functional capacities, European companies have the option to invest in collaborative robots, to provide a better working environment, or to export the part of production to the East.

In this specific case study, the best solution is to invest in collaborative robots and to keep productive workers longer in employment. There are also five further directions for the research, where some other factors should be considered which could influence decisions on the human resource policy:

(a) The environmental consequences and the reverse logistics should be better investigated in the context of the perturbation of delays, continuing some considerations also presented in [28-32], where the approach, already suggested in 2005, is good to start to consider the reverse logistics in value chain in general [33]. For evaluating the parameters, sometimes also fuzzy approach can support several environmental and location decisions as described by Kovačić, Tuljak-Suban and many others who were using MRP Theory for developing a skeleton for modelling the environmental and location decisions [34-38]. All these approaches can be combined by the gravity model of human resources .

(b) Since environmental and other taxes are not included in the calculations above, this will be a subject of further research, especially considering taxes as the source of funds for investments in smart technologies and social innovation [39-42] which support the decissions to attract new skilled workers to the region of productio [43-48]. These studies show that the public investments and subsidies can be subject of better attraction of the human resources and consequently, it can influence decissions on taxation and about the dillemas to invest in the education of incoming young workers in the region [46, 48], while the model can lead also to the spatial games, as suggested in [49].

(c) Also, the quality of products which could influence the differentiation of prices and create value [50] should be further studied, if a production is considered at different locations and transportation damages could additional appear or at list should be insured;

(d) The trajectory of functional decline of workers and investments in the workplace ergonomics should be carefully studied. Age-productivity profiles should be investigated more precisely for different groups of workplaces [5];

(e) How to organise organisational learning for better understanding the impacts and response to latency in ageing [51, 52] is also the subject of further research.

References

[1] European Commission, The 2018 Ageing Report, European Commission (2018). 1-406
[2] A. Walker, The emergence of age management in Europe. International Journal of Organisational Behaviour, 10(1), (2005), 685-697.
[3] EU-OSHA, Cedefop, Eurofound and EIGE, Joint report on Towards age-friendly work in Europe. (2017) 1-90
[4] M. Dalecki, M. Kalicinski, F. Steinberg, and O. Bock, Age-related operator deficits in a realistic instrument-control task: Assessment of possible motor, cognitive and mental causes. International Journal of Industrial Ergonomics, 59 (2017) 100-107
[5] A. Börsch-Supan, M. Weiss, Productivity and age: Evidence from work teams at the assembly line. The Journal of the Economics of Ageing 7 (2016) 30–42.
[6] M. Calzavara, D. Battini, D. Bogataj, F. Sgarbossa, I. Zennaro, Ageing workforce management in manufacturing systems: state of the art and future research, International Journal of Production Research, (2019) DOI: 10.1080/00207543.2019.1600759
[7] M. Bogataj, L. Bogataj, Supply chain coordination in spatial games, International Journal of Production Economics, 71(1-3) (2001) 277-286.
[8] M. Bogataj, L. Bogataj, On the compact presentation of the lead times perturbations in distribution networks. International journal of production economics, 88(2) (2004) 145-155.
[9] L. Bogataj, M. Bogataj, The study of optimal additional investments in capacities for reduction of delays in value chain, International Journal of Production Economics, 108 (2007) 281-290.
[10] R.W. Grubbström, Transform methodology applied to some inventory problems. Z. Betriebswirtsch, 77 (3) (2007) 297-324.
[11] D. Bogataj, M. Bogataj, NPV approach to material requirements planning theory: a 50-year review of these research achievements. International Journal of Production Research, 56 (2018) 10.1080/00207543.2018.1524167
[12] K. Landau, H. Rademacher, H. Meschke, et al., Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects. International Journal of Industrial Ergonomics 38 (2008) 561–576
[13] K. Schaub, G. Caragnano, B. Britzke, R. Bruder, The European Assembly Worksheet. Theoretical Issues in Ergonomics Science, 14(6) (2013) 616-639.
[14] A. Aittomäki, E. Lahelma, E. Roos, P. Leino-Arjas, P. Martikainen, Gender differences in the association of age with physical workload and functioning. Occup. Environ. Med., 62 (2005) 95–100.
[15] S. Aiyar, C. Ebeke, X. Shao, The Impact of Workforce Aging on European Productivity, Working Paper No. 16/238 IMF, (2016), 1-29
[16] D. Battini, M. Faccio, A. Persona, F. Sgarbossa, New methodological framework to improve productivity and ergonomics in assembly system design, Int. J. of Industrial Ergonomics, 41 (2011) 30–42.
[17] A. Otto, A. Scholl, Incorporating ergonomic risks into assembly line balancing, European Journal of Operational Research, 212 (2011) 277–286.
[18] E. Estevez, A.S. Garcia, J.G. Garcia, J.G. Ortega, An UML based approach for designing and coding automatically robotic arm platforms. Rev. Iberoamericana de automatica e informatica industrial, 14(1) (2017) 82-93.
[19] D. Bogataj, D. Battini, M. Calzavara, A. Persona, The ageing workforce challenge: investments in collaborative robots or contribution to pension schemes, from the multi-echelon perspective. International journal of production economics, 210 (2019) 97-106.
[20] D. Battini, M. Calzavara, F. Sgarbossa, A. Persona, MRP Theory supporting trade-off between investments in collaborative robots and production in foreign countries for a water pumps supply chains. SOR'17 Proceedings, (2017) 229-234.
[21] M. Bogataj, D. Bogataj, Optimal retirement age and related database for the transportation industry. Data driven supply chn, (2017) 417-424.
[22] R.W. Grubbström, On the application of the Laplace transform to certain economic problems, Manag. Sci., 13 (1967) 558-567.
[23] M. Bogataj, R.W. Grubbström, L. Bogataj, Efficient location of industrial activity cells in a global supply chain, International Journal of Production Economics, 133(1) (2011) 243-250.
[24] J. Usenik, M. Bogataj, A fuzzy set approach for a location-inventory model, Transportation planning and technology, 28(6) (2005) 447-464.
[25] M. Bogataj, R.W. Grubbström, On the representation of timing for different structures within MRP theory. International Journal of Production Economics, 140(2) (2012) 749-755 .
[26] M. Bogataj, R.W. Grubbström, Transportation delays in reverse logistics, International Journal of Production Economics, 143(2) (2013) 395-402
[27] D. Kovačić,, M. Bogataj, Reverse logistics facility location using cyclical model of extended MRP theory. Central European Journal of Operations Research, 21(1) (2013) 41-57.
[28] D.Kovačić, E. Hontoria, L. Ros Mcdonnell, M. Bogataj,. Location and lead-time perturbations in multi-level assembly systems of perishable goods in Spanish baby food logistics. Central European Journal of Operations Research,, 23(3) (2015) 607-623.
[29] D.Kovačić, M. Bogataj, Net present value evaluation of energy production and consumption in repeated reverse logistics. Technological and economic development of economy 23(6)(2017) 877-894.
[30] D.Kovačić, M. Bogataj,. Reverse logistics facility location using cyclical model of extended MRP theory. Central European Journal of Operations Research, 21(1)(2013) 41-57.
[31] S. Drobne, M. Bogataj, A method to define the number of functional regions: An application to NUTS 2 and NUTS 3 levels in Slovenia. Geodetski vestnik 56(1)(2012) 105-150.
[32] D.Kovačić, M. Bogataj,. Reverse logistics facility location in extended MRP theory. *SOR '11 proceedings*. Ljubljana: SDI_SOR.(2011) 239-244.
[33] L. Bogataj,. M. Bogataj,.. Reverse logistics in value chain. *SOR '05 proceedings*, Ljubljana: SDI_SOR, (2005) 199-205.
[34] D. Tuljak Suban, M. Bogataj. An optimal ordering cycle at interactions of fuzzy parameters and high disposal fees of food or drug supply systems. IFAC-PapersOnLine, 48(3)(2015) 2374-2379,
[35] M. Bogataj, S. Drobne, D. Tuljak Suban,. A fuzzy approach to forecasting the attractiveness of regions for human resources. Industrial engineering : innovative Networks : annals of industrial engineering 2011. London: Springer. cop. (2012) 375-384.
[36] S. Drobne, M. Bogataj, D. Tuljak Suban, U. Železnik, Regression-neuro-fuzzy approach to analyse distance function in internal inter-regional migrations in EU countries. SOR '11 proceedings. Ljubljana: SDI_SOR (2011) 171-176,
[37] D. Kovačić, J. Usenik, M. Bogataj, Optimal decisions on investments in urban energy cogeneration plants - extended MRP and fuzzy approach to the stochastic systems. International journal of production economics 183(part B) 583-595.
[38] M. Bogataj, D. Tuljak Suban, S. Drobne, Regression-fuzzy approach to land valuation. Central European Journal of Operations Research, 19(3)(2011) 253-265.
[39] S. Drobne, M. Bogataj, M. Krivic, A. Lisec, Dynamics and local policy in commuting: attractiveness and stickiness of Slovenian municipalities. SOR '11 proceedings. Ljubljana: SDI_SOR. (2011) 323-328,
[40] A. Lisec, S. Drobne, M. Bogataj, The influence of the national development axes on the transaction value of rural land in Slovenia. Geodetski vestnik 52, (1)(2008) 54-68.
[41] S. Drobne, M. Bogataj. Intermunicipal gravity model of Slovenia. SOR '05 proceedings, Ljubljana: SDI_SOR. (2005) 207-212.
[42] S. Drobne, M. Bogataj., Evaluating functional regions for servicing the elderly. SOR '13 proceedings, Ljubljana: SDI_SOR (2013) 331-336.
[43] V. Roblek, M. Meško, V. Dimovski, J. Peterlin, Smart technologies as social innovation and complex social issues of the Z generation, Kybernetes, 48(1) (2019) 91-107.

[44] S. Drobne, M. Bogataj. The impact of public investments in facilities on the potential housing market for older persons. *Facilities*, 2017, Vol.35, no. 7/8, (2017) 422-435.
[45] S. Drobne, M. Bogataj.. Optimal allocation of public service centres in the central places of functional regions. IFAC- PapersOnLine, 48(3)(2015) 2362-2367.
[46] P. Janež, S, Drobne, M.Bogataj. Forecasting dynamics of daily commuting to work to other municipality in the case of changing taxation policies. Lecture notes in management and industrial engineering. Cham: Springer. (2018) 105-112,
[47] P. Janež, M.Bogataj. The impact of real estate taxations on the inter-municipal migration which influences the housing construction dynamics. Lecture notes in management and industrial engineering, Cham: Springer. (2018) 41-48.
[48] P. Janež, M.Bogataj. S.Drobne, Impact of the real estate taxation and municipal revenue on dynamics of internal migration : case study for city Municipal of Ljubljana Geodetski vestnik 60(4)(2016´) 644-684.
[49] M. Bogataj, L. Bogataj, Supply chain coordination in spatial games. International journal of production economics 71(1-3) (2001) 277-286.
[50] K. Božič, V. Dimovski, Business intelligence and analytics for value creation: the role of absorptive capacity. Int. j. inf. manage., 46 (2019) 93-103.
[51] T. Arh, B. Jerman-Blažič, V. Dimovski, The impact of technology-enhanced organisational learning on business performance: an empirical study, The Journal of East European Management Studies, 17(3) (2012) 369-383.
[52] J. Žnidaršič, V. Dimovski, Retaining older workers: fields of action - constituting a comprehensive age management model, J. appl. bus. res., 25(4) (2009) 85-98.