Value Analysis as a Mechanism to Reduce the Complexity of the Selection of the Resources System for Agile/Virtual Enterprises in the Context of Industry 4.0

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The selection of the resources system (SRS) is an important element in the integration/project of Agile/Virtual Enterprises (A/V E) because its performance is dependent of this selection, and even of its creation. However, it remains a difficult matter to solve because is still a very complex and uncertain problem. We propose that using Value Analysis (VA) in the pre-selection of resources phase represents a significant improvement of the SRS process. The current literature fails to formally address the pre-selection phase and none of the resource selection models incorporate the resources value and its consequence in the complexity of the selection process. Whereby, ours developed model with VA constitutes an innovative approach towards greater sustainability in the configuration of A/V E in the context of Industry 4.0, where a massive interconnection among enterprises is expected and consequently the increase of the selection process complexity. After the construction of a demonstrator tool for a set of the problem formulations, this paper verifies by computational results the thesis regarding the benefits of applying VA to the SRS process: VA reduces the complexity of the SRS process, even ensuring that the final system of resources achieve higher quality/value grade.

Keywords: *Agile/Virtual Enterprises, Selection of the Resources System, Resources System Value, Value Analysis, Complexity Management, Industry 4.0.*

1. INTRODUCTION

The initial subsistence tools-based economy evolved towards nowadays digital and global context where digital technology and virtual collaboration sustains both the manufacturing processes and relations among people (social networks) and companies (virtual organizations) [1]. It was the work of Drucker and the researchers of the Iacocca Institute [2, 3] which gave rise to the concept of the virtual enterprise associated with the concept of creating dynamic networks of enterprises. This paper relies on a concept of Agile/Virtual Enterprise (A/V E) based on a hierarchical multi-level process which aims to satisfy the basic properties of a virtual enterprise. It is characterized as a dynamic, reconfigurable global network, aiming to satisfy requirements for integrability, distributivity, agility, and virtuality as factors of competitiveness vis-à-vis conventional enterprises [4-7]. An A/V E should be a dynamic and virtual structure capable of reacting to a business opportunity, in which not every partner enterprise involved, whether wholly or partially, would lose its physical and cultural identity upon deactivation at the end of the product lifecycle. Even during the operation phase of the A/V E, the setting may change to ensure business alignment with market demands, translated by identifying the reconfiguration opportunities and continuing adjustment or reconfiguration of VE network, to meet unexpected situations or to keep the continued competitiveness and maximum performance [8].

The development of such more dynamic and complex types of enterprises have led to an upsurge in research interest in the process of the selection of the resources system (SRS). The main reason for this is due the fact that the performance of such SRS process will influence the performance of the A/V E, i.e., its operation cost, quality/value, time spent, and its agility to reconfigure. Moreover, the concept of Industry 4.0 (I4.0), namely with the digitalization, gives to the enterprises new opportunities to access new markets and supply chains [9], that means the fitness to candidate to any A/V E. In spite of few authors consider that I4.0 is still a vision of the future [10] or the research projects do not reach all the initial goals [11] the transformation is underway and the connectivity among enterprises is seen as important and necessary.

By "connectivity" is usually understood the communication relationship, i.e., more precisely the channels for communication transactions and business relationship, among the entities, i.e. among the enterprises within the context of this paper. However, in the context of complexity management in organization discipline

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the term “connectivity” has another meaning, referring to the level of holonic properties of an organisation or network of organisations. This aspect is out of scope of this paper.

This work defines resource as any identifiable mean that enables a task accomplishment in the task plan (TP). Because a resource can be constituted by other resources, from the point of view of an A/V E promoter, partner enterprises can also be designated as resources. The combination and integration of partner enterprises brought together to execute a TP is the resources system, it can be thought of as a type of supply chain for the A/V E. In spite of each author define his own SRS problem, in a broad sense the problem consists of selecting a system of resources (combinatorial problem) which optimizes the total value of the system’s objec–tive function (including multi-criterion), for the pro–duction of a single product (independently of the quan–tities), in cases in which several candidate resources compete for each part of the TP. The SRS problem is very complex because can be of exponential complexity and a multi-criterion optimization problem also, de–pending how each author formulates the selection problem. Cumulatively, in the context of I4.0, where a massive interconnection among enterprises is expected [12], much more resources will be able to candidate to an A/V E and consequently the increase of the selection process complexity.

An extensive literature review made by Pires et al. [13] has demonstrated that the models for the resolution of the SRS for A/V E vary widely in terms of frame–works, methods, classifications, and tools used, and still presented the following gaps: some models have neg–lected the pre-selection phase, incorporating it into the final selection; treated the selection requisites in different ways and none considered all the requisites presented; none of the models incorporated formally the value con–cept; neither of the models contemplated the decision making stage to create an A/V E through a comparative analysis with a conventional process; none of the revised approximation algorithms, applied to the problem, spe–cified performance measures. As a resume, the models should guarantee: (1) more effectiveness - the solutions must guarantee the feasibility of the task plan; and (2) more efficiency - the solutions must be performed in useful time.

In order to improve the shortcomings afore pointed, this work proposes the integration of value analysis (VA) in the pre-selection of resources phase. More con–cretely, the main objective of this paper is to de–monstrate that VA integration reduces the complexity of the SRS process, even ensuring that the final system of resources achieve higher quality/value grade.

VA was created in 1947 by Lawrence Miles at General Electric [14] and is an established methodology widely applied that has evolved with the changing competitive environment [15, 16]. VA permits the identification of a set of objectives and business impro–vement guidelines [17] and is a well-known structured method to increase value and support the selection of the most valuable solution [18]. The main advantages of VA are: improved decisions; greater efficiency of resource use and time, with better results; product enhancement; increased competitiveness due to tec–hnical and organizational innovation; nurturing a culture of value creation; improved internal communications and knowledge of key success factors for the orga–nization. VA is actually more than a tool for reducing costs by incorporating a whole philosophy of value creation, with great potential in a wide range of fields and with results and benefits in far-reaching areas. It is, in fact, a paradigm almost totally lacking in the lite–rature of existent models of selection of resources and hence the importance of this work.

The rest of this paper is organized as follows. In Section 2 is analysed the selection process in terms of its formulation and effort. After that, is presented in section 3 our SRS model with VA, and in Section 4 the demonstrator and its assumptions. In section 5 we give numerical examples to compare the results in order to demonstrate our objective for this paper. Finally, the conclusion including summary of the main results and some directions for future research is given in Section 6.

2. ANALYSIS OF THE SELECTION PROCESS OF THE RESOURCES SYSTEM

As it was referred before, the problem of SRS to integrates an A/V E can be formulated from different forms or instances. However, our activity-based model, defined in IDEF0 [19] for SRS is sufficiently flexible to adjust for any A/V E selection requisites, i.e., for different formulations of the problem. For our project we consider that these formulations may be framed with two types of methods [19]:

Fractioned Selection Method (FSM) – It is the selection method which defines the system of resources to integrate the A/V E project bearing in mind its performance in the execution of an association of tasks (including the transport ones) belonging to the tasks plan of the production life cycle of the product.

Dependent or Integral Selection Method (DSM) – It is Selection method which defines the system of resources to integrate the A/V E project bearing in mind its performance in the total execution of all tasks (inc–luding the transport ones) belonging to the tasks plan of the production life cycle of the product.

Here in this paper, we will address a case of the DSM, the Dependent or Integral Selection Method without Pre-selection of Transport Resources (DSMWO) – It is a subset of the Dependent or Integral Selection Method where the parameters that reflect the distributiveness of the resources, as the transport time and cost, are estimated. However, independently of the method, our SRS model is divided into two main phases: (1) the resources pre-selection; and (2) final selection of the resources system.

Considering that:

- It is known a plan of processing tasks with their restrictions and requisites asked by the A/V E Promoter;
- Each task is executed by only one resource, i.e., there is no task split;
- The resources supply its necessary data for each of the phases of the selection;
- There is no selection of transport resources, but will be considered estimated costs and times of transportation through the distances between resources;

- The goal is to optimize an objective function that translates the better performance (or guarantees a good performance when it is not possible to certificate the optimal solution) of the resources system selected to perform the entire plan of processing tasks.

Figure 1 represents graphically, the results of the resources pre-selection phase [20]. What we have is one plan of processing tasks allocated to the pre-selected resources per task that are represented by dots and designated by r_{ij} inside each task T_i.

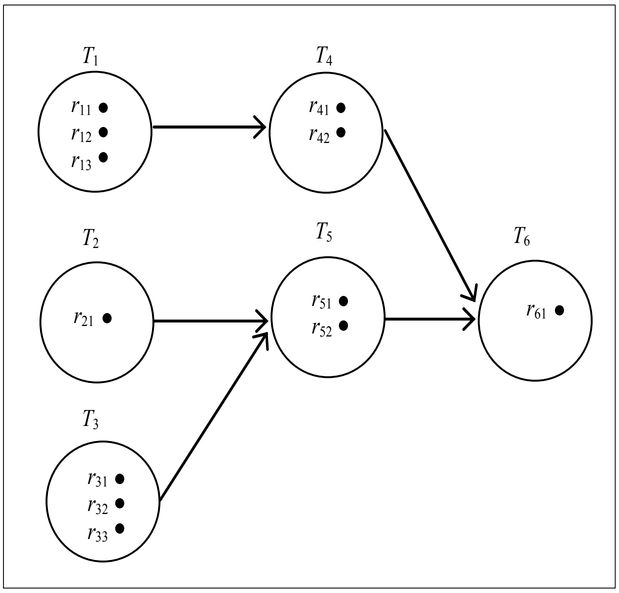

Figure 1. An example of the pre-selected resources for a plan of processing tasks.

For each pair of pre-selected resources inside each consecutive processing tasks, there are probably dif–ferent transportation features (distance and consequently time and costs), that can be translated by dashed arrows in Figure 2.

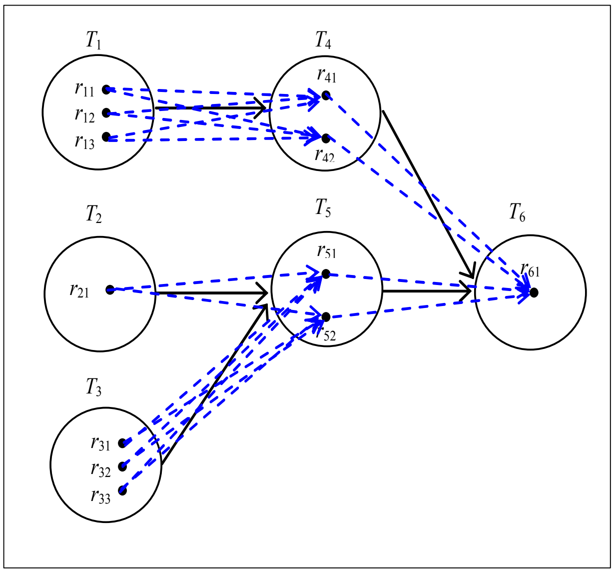

Figure 2. An example of the total transportation tasks to be considered in the SRS.

Afterwards, in the second phase of the process should be selected the better system of resources thro–ugh an objective function (can be multi-criterion), con–sidering the possible combinations (combinatorial prob–lem) of those pre-selected resources taking into account the necessity of transport between two consecutive pro–cessing tasks. For example, the solution could be found as the system of resources $<r_{11}, r_{21}, r_{32}, r_{42}, r_{51}, r_{61}>$.

The performance of these two phases is critical for the project and for the agility reconfiguration of the A/V E. However, the performance of the second phase is influenced by the results of the first, namely by the “quality” of the pre-selected resources and by its quantity per task (k). According to Ávila et al. [21], for the selection method that we are dealing, the DSMWO, we got the following effort expressions for the pre-selection phase and for the final selection of the resources system phase:

$$\textit{Total Effort of the Pre-selection}_{\_DSMWO} \propto n(St_{PS} + e * Xc) \quad (1)$$

$$\textit{Total Effort of the Final Selection}_{\_DSMWO} \propto St_{FS} + k^n \quad (2)$$

Considering:

e - Effort factor in the pre-selection of one resource and equal for any resource independently of the task;

Xc - Number of pre-selection candidate resources per task after the search activity;

k - Number of pre-selected resources per task and considered equal for all the processing tasks;

n – Total number of processing tasks;

St_{PS} – Total set up for the pre-selection phase per each task;

St_{FS} - Total set up for the final selection phase.

The expressions (1) and (2) gives us the information that while the pre-selection effort is polynomial, for the second phase, the effort grows exponentially with the number of tasks and with the number of pre-selected resources. In fact, an instance of the SRS problem, for the second phase, was formulated for the DSMWO and several simulation experiences were carried out in order to test the practical usage of an exact solution algorithm (bintprog solver of Matlab). The results obtained for different combinations of n and k, in terms of average computational time (in seconds), are shown in Figure 3.

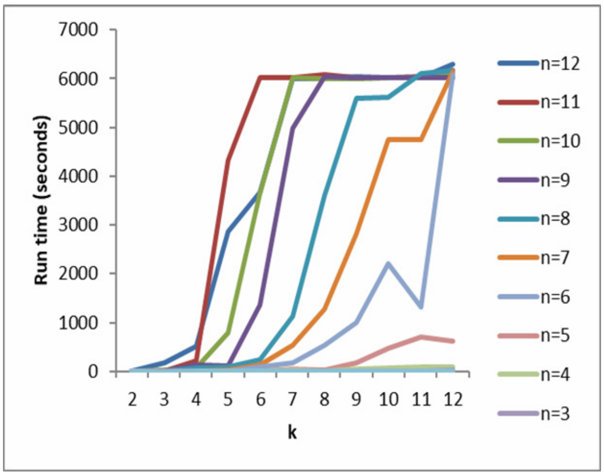

Figure 3. Computational results with bintprog solver [22].

As expected, it can be observed that the compu–tational time to perform the optimization process inc–reases with k and n. For large values of n the growing of computational times compromises the application of the algorithm even with smaller values of k. These findings show that it is crucial to use other approaches to solve medium or large instances of the problem. In our rese–arch we subscribe the development of two comple–mentary approaches to reduce the complexity of the broker activity in the SRS process:

(1) For the pre-selection phase, the integration of value analysis as a mean to avoid the pre-selection of lower value resources and consequently, the final resources system will have higher quality/value grade (effectiveness improvement), and because the pre-selected resources will be less, then the final selection time will reduce (complexity reduction);

(2) For the final selection phase, the integration of approximate algorithms, as e.g., genetic algorithms, to tackle large instances of the problem that cannot be solved by exact algorithms.

As was referred in section 1, the scope of this work will handle with the approach (1).

3. THE ACTIVITY MODEL WITH THE INTEGRATION OF VALUE ANALYSIS

The main objective of building the VA integration mo–del into the pre-selection of resources phase, it relates to the application of its steps and techniques in the de–velopment of the algorithm for evaluating pre-selection candidate resources.

3.1 Updating of the Pre-Selection Requisites

The main pre-selection requisites found and analysed in the existing selection models are associated to the: Product/Task, Product/Task Project, Production Pro–cess, and Production Planning, but are not incorporated into any formal system organization [13].

Table 1. Levels and systems of requisites for the pre-selection.

Level	Systems of Requisites
1	**Product/Task** (product functional specifications for each task, such as design, quality control and materials specifications) **Product/Task Project** (product design and modeling tasks, for example the calculations, CAD models of product and assembly) **Production Process** (operations and their task sequencing including specifications for each operation identifying processes, types of machines and tools, monitoring tools, operational dimensions and operational tolerances) **Production Planning** (planning and scheduling, for example regarding the quantities needed between time intervals; the start and completion of tasks)
2	**Quality System** (quality management systems, guarantees, service level, customer quality focus, total quality management) **Financial System** (economic/financial ratios, value creation, financial stability, contracting, financial markets) **Synergies System** (synergy potential, localization, strategic issues, organizational relations, cultural issues)

These requisites should be the subject of detailed specification for the definition and quantification of the VA inte–gration model and considered in level 1.

An extended bibliographic review of the main requisites of resources selection in virtual and conventional enterprises, made with the works of [23-30], led us to consider 3 more sets of systems of requisites associated to the quality, financial, and synergies for level 2. Then, based on our bibliographic research, Table 1 presents the novel set of pre-selection requisites, grouped into two levels, that we propose for the pre-selection.

3.2 The Adequacy of the Pre-Selection for the VA

Indirect negotiation is the most commonly used activity for the pre-selection of resources, because it is flexible and adjusts to the different requirements of each A/V E. A primary objective of pre-selection is to evaluate eli–gible resources and VA promises to make a significant contribution as a tool for this activity. Figure 4 represents the indirect negotiation activity with VA integration in IDEF0 modelling language.

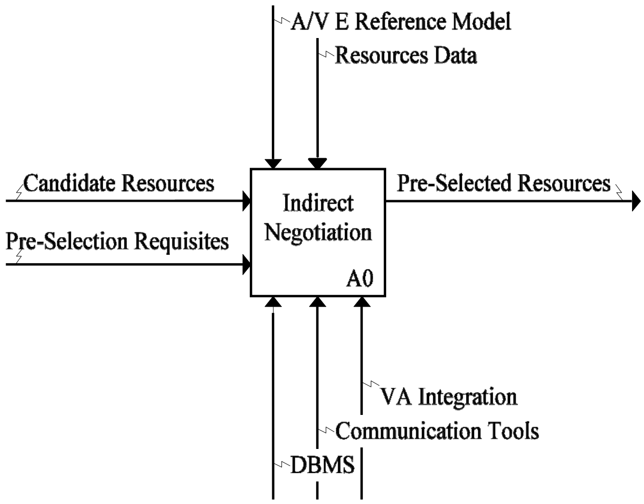

Figure 4. Representation of indirect negotiation with VA integration

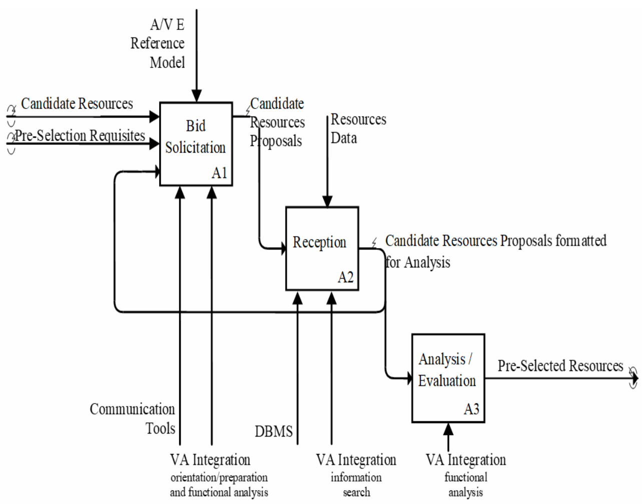

Figure 5. Indirect negotiation with VA steps

During indirect negotiation, tasks and their requisites are identified and bids are solicited (bid solicitation). Afterwards the candidate resources respond and tender their bids for each task (reception) and then the proposals are then reviewed and either accepted/rejected (analysis/evaluation). Figure 5 illustrates, in IDEF0 language, the three main phases of indirect negotiation (A1 - Bid Solicitation, A2 - Reception and A3 - Analysis/Evaluation) with the VA tool separated into its component mechanisms.

At activity A1 the VA integration occurs trough the orientation/preparation mechanism. It consists of a preparatory phase to ensure the best possible conditions for the process, a full and clear definition of the VA, its objectives and constraints and the scheduling of resources (human, physical, temporal, financial, etc.). In the intermediate stage, activity A2, VA integration consists of receiving and formatting of proposals and the subsequent search for any additional information and making any necessary adjustments. This stage corresponds to the VA information search phase. Finally, with the activity A3, VA incorporates its functional analysis through the following tasks: evaluating the objective function (*OF*) of level 1 systems; if necessary, the definition of degrees of flexibility for this level; the evaluation of the *OF* of level 2 systems; the weighting of systems and its requisites; and determining the value of the objective function for each resource (*VOF*).

The objective function of the level 1 systems is generally of the boolean type. If, for any system of requisites, a minimum level for any candidate is not achieved, then we can define degrees of flexibility and reset the minimum values of acceptance for some or all the requisites. If candidate resources fall within the range of acceptance, they pass to level 2 of evaluation. Next the candidates are evaluated regarding the *OF* of level 2 systems. This involves maximizing the parameters under consideration, in which minimum levels of acceptance may be defined. Afterwards, weighting the level 2 systems of requisites occurs in order to evaluate the candidate resources, based on their relative importance. Our model intends to leave this option open to the A/V E promoter, so that it may take their assumptions and project circumstances into consideration. Finally, the overall value of the candidate resources is determined in order to pre-select them.

The evaluation of the level 2 systems (FQS_r_{ij}; FFS_r_{ij}; FSS_r_{ij}) and the determination of the *VOF* are represented below considering the following assumptions and notations:

r_{ij} - candidate resource j to pre-selection of the task T_i

FQS - objective function of quality system

FFS - objective function of financial system

FSS - objective function of synergies system

PQi_r_{ij} - pre-selection parameters of quality system for the resource r_{ij}

$PF_i\_r_{ij}$ - pre-selection parameters of financial system for the resource r_{ij}

PSi_r_{ij} - pre-selection parameters of synergies system for the resource r_{ij}

ΦSQ_i - weighting of quality system requisites

ΦSF_i - weighting of financial system requisites

ΦSS_i - weighting of synergies system requisites

$$VOF = \sum ((\Phi SQ_i * PQ_i\_r_{ij}) + (\Phi SF_i * PFi\_r_{ij}) + (\Phi SS_i * PS_i\_r_{ij})) \quad (3)$$

Subject to:

$$FSQ\_r_{ij} = \sum (\Phi SQ_i * PQ_i\_r_{ij}) \geq 5$$
$$FSF\_r_{ij} = \sum (\Phi SF_i * PF_i\_r_{ij}) \geq 5$$
$$FSS\_r_{ij} = \sum (\Phi SS_i * PS_i\_r_{ij}) \geq 5$$

3.3 Comparison of Complexity Measures for the Two Approaches – Without and With VA

Recalling the expressions (1) and (2) of the section 2 for the effort for the two phases of the SRS, we can say that the order of complexity (*O*) is:

$$O(Pre\text{-}Selection\_{_{DSMWO}}) = O(n*Xc) \quad (4)$$

$$O(Final\ Selection\_{_{DSMWO}}) = O(k^n) \quad (5)$$

Considering that *Xc* is equal for the two approaches, then the complexity of Pre-selection is equal. Now, for the final selection without VA let us consider the $O(k_w^{\ n})$, and with VA the $O(k_v^{\ n})$. The problem remains as exponential complexity. However, the experimental results of section 5 will show that:

kw > kv, then O(kwn) > O(kvn)

4. DEMONSTRATOR TOOL

Our main objective is to demonstrate that VA reduces the complexity of the SRS process. We designed and built a demonstrator tool, using MATLAB, to test this assumption, for a case of the selection method that we are dealing, the DSMWO. It should simulate and plan the pre-selection and consequent final selection both with and without the VA model.

The global key assumptions in our model and respective demonstrator tool were:

- No concrete TP is set for any particular product, so as not to limit the demonstrator to any plan in concrete;

- The task complexity is the same for any T_i;

- Some restrictions are incorporated, namely the generation of random values for the candidate resources parameters, given the scale used in the VA (0-10);

- The number of resources pre-selected (*k*) for each T_i will be equal to the minimum k found for all tasks in the respective TP;

- The weighting of the systems and their associated requisites of level two will be established at the discretion of the user, i.e., the weights are introduced as variables in the demonstrator in order to make it as comprehensive as possible.

For the Pre-Selection Activity were considered the following:

- For pre-selection without VA the pre-selected resources (*k*) are the minimum value established within the TP meeting the requisites for pre-selection defined as level 1;

- For the pre-selection with VA the pre-selection candidate resources must attain level 1 pre-selection requisites, while also evaluating those at level 2 and determining the value objective function. Candidate resources must obtain a positive VA value, i.e., value ≥ 5 in the three systems of level 2 (quality, financial, and synergies).

For the Final Selection Activity, the demonstrator evaluates the pre-selected results both with and without VA in the final selection algorithm and then selects the best system of resources for the TP for both situations. A case of the selection method DSMWO was consi–dered as expose below. Taking into consideration the previous notation already defined for T_i, n, and K, and adding the following:

r_{ij} - is the pre-selected processing resource $_j$ to perform the processing task T_i;

C_{ij} - is the processing cost of task T_i with the resource r_{ij};

$T_{ij,lm}$ - is the affectation of the transportation between the resource r_{ij} and resource r_{lm} allocated at two adjacent tasks of the *TP*;

$TC_{ij,lm}$ - is the transportation cost between the resource r_{ij} and resource r_{lm} allocated at two adjacent tasks of the *TP*.

The goal for the problem treated here consists of selecting a resources system minimizing total production costs (processing and transport). The integer programming formulation of the problem is given by:

$$\text{Min FC} = \sum_{i=1}^{n}\sum_{j=1}^{k} C_{ij} * r_{ij} + \sum_{i=1}^{n}\sum_{l=1}^{n}\sum_{j=1}^{k}\sum_{m=1}^{k} TC_{ij} * T_{ij,lm} \quad (6)$$

Subject to:

$$\sum_{j=1}^{k} r_{ij} = 1, \quad i = 1,2,...,n \quad (7)$$

$$r_{ij} = 0,1 \quad \text{(binary variable)}$$
$$T_{ij,lm} = 0,1 \quad \text{(binary variable)} \quad (8)$$

$$r_{ij} + r_{lm} - 2T_{ij,lm} \geq 0, \quad \forall T_{ij,lm}$$
$$-r_{ij} - r_{lm} + T_{ij,lm} \geq -1, \quad \forall T_{ij,lm} \quad (9)$$

The objective function of cost (6) considers the two types of costs, processing and transportation. The first restriction (7) imposes that each processing task is performed only by one resource. The next group of restrictions (8) force the variables to be binary. The last two restrictions (9) demand that when each pair of adjacent resources is selected then its transportation is also selected. Simultaneously these restrictions permit a single resource to be selected without selecting the other adjacent resource.

5. EVALUATION OF THE COMPUTATIONAL RESULTS

A plan of simulations was defined to pre-select the candidate resources with and without VA. These pre-selection results are then incorporated into a final selection algorithm, in order to test our assumption: the contribution of the VA in SRS as a mechanism to reduce the complexity of the process. The values of the inputs of the plan of simulations are represented in Table 2 and detailed below.

Table 2. Inputs of the plan of simulations.

Plan of Simulations – Inputs		
Pond	**Xc**	**n**
identical weights for each level 2 system and their associated requisites	10	2, 3, 4, …, processing capability of the demonstrator tool
	. . .	. . .
	processing capability of the demonstrator tool	2, 3, 4, …, processing capability of the demonstrator tool

Pond **(weighting):** Identical weights are established for each level 2 system and their associated requisites (presented in the Table 1). The weighting of the systems of requisites for pre-selection (level 2) and respective requisites were introduced as variables in the demonstrator tool in order to maintain the most comprehensive range possible of the instrument. Empirically determined weights from current research will be introduced in the near future.

Xc **(number of candidate resources):** The candidate resources (*Xc*) dimension is intended to gradually and constantly increase as far as the demonstrator tool allows, in order to draw conclusions regarding their influence in either model or other variables. Dimensions are defined as equal to the number of candidate resources (*Xc*) for each task within the same TP. The plan of simulations starts with $Xc = 10$ to ensure that at least one resource is pre-selected ($k = 1$) for each of the tasks in the TP. The size of *Xc* is increased at intervals of five candidate resources, until the demonstrator is unable to complete the simulation or exceeds the time limit without obtaining the optimal solution.

n **(number of tasks):** The TP dimensions are constant for the different dimensions of the number of candidate resources (*Xc*) to obtain a comparative basis which allows us to draw conclusions about the performance of the model. Different TP dimensions are considered, starting with two tasks ($n = 2$) and increasing one by one until the demonstrator is unable to complete the simulation or exceeds the time limit defined (7200 sec.) without obtaining the optimal solution.

The computational results are expressed in the Table 3 following the plan of simulations defined before.

As Table 3 demonstrates, the final system value obtained with the application of VA is superior to that obtained without it. In terms of percentage, considering that the systems value without VA for all the simulations represents 100%, the same value with VA has the average value of 105.5% (see Figure 6). It represents an average increment of the value of the final resource systems in 5.5%, between a range of a minimal of 0% and a maximum of 14.5%.

Table 3. Computational results.

		Without VA				With VA			
Xc	***n***	***k***	***t* (sec.)**	**Final System**	**System Value**	***k***	***t* (sec.)**	**Final System**	**System Value**
10	2	5	2	$r_{1,6}$; $r_{2,6}$	12.13	1	0	$r_{1,10}$; $r_{2,8}$	12.75
	3	5	1	$r_{1,5}$; $\mathbf{r_{2,6}}$; $r_{3,1}$	16.49	2	0	$r_{1,4}$; $r_{2,3}$; $r_{3,4}$	18.63
	4	6	8	$r_{1,7}$; $r_{2,7}$; $r_{3,5}$; $r_{4,1}$	22.26	3	1	$r_{1,9}$; $r_{2,7}$; $r_{3,3}$; $r_{4,2}$	25.36
	5	6	20	$r_{1,9}$; $r_{2,1}$; $r_{3,3}$; $r_{4,9}$; $r_{5,2}$	31.62	2	0	$r_{1,9}$; $r_{2,1}$; $r_{3,10}$; $r_{4,5}$; $r_{5,2}$	32.49
	6	6	176	$r_{1,7}$; $r_{2,10}$; $r_{3,6}$; $r_{4,9}$; $r_{5,4}$; $r_{6,9}$	36.99	3	4	$r_{1,7}$; $r_{2,10}$; $r_{3,3}$; $r_{4,4}$; $r_{5,7}$; $r_{6,9}$	38.39
	7	5	317	$r_{1,4}$; $r_{2,10}$; $r_{3,7}$; $r_{4,10}$; $\mathbf{r_{5,2}}$; $r_{6,6}$; $r_{7,2}$	43.71	2	0	$r_{1,1}$; $r_{2,10}$; $r_{3,1}$; $r_{4,8}$; $r_{5,6}$; $r_{6,6}$; $r_{7,2}$	44.80
	8	5	1025	$r_{1,4}$; $r_{2,8}$; $r_{3,2}$; $r_{4,9}$; $r_{5,4}$; $r_{6,6}$; $r_{7,1}$; $r_{8,5}$	49.27	3	25	$r_{1,4}$; $r_{2,8}$; $r_{3,2}$; $r_{4,3}$; $r_{5,6}$; $r_{6,8}$; $r_{7,2}$; $r_{8,1}$	50.36
	9	5	1119	$r_{1,10}$; $r_{2,1}$; $r_{3,2}$; $r_{4,7}$; $r_{5,7}$; $r_{6,6}$; $r_{7,2}$; $r_{8,8}$; $r_{9,7}$	56.89	2	2	$r_{1,10}$; $r_{2,1}$; $r_{3,8}$; $r_{4,1}$; $r_{5,7}$; $r_{6,9}$; $r_{7,2}$; $r_{8,2}$; $r_{9,7}$	59.63
	10	5	6092	$r_{1,4}$; $r_{2,6}$; $r_{3,9}$; $r_{4,5}$; $r_{5,7}$; $r_{6,10}$; $r_{7,1}$; $r_{8,6}$; $r_{9,8}$; $r_{10,2}$	60.39	1	0	$r_{1,10}$; $r_{2,8}$; $r_{3,9}$; $r_{4,9}$; $r_{5,7}$; $r_{6,8}$; $r_{7,2}$; $r_{8,3}$; $r_{9,6}$; $r_{10,4}$	64.71
	*11	5	7210	$r_{1,3}$; $r_{2,9}$; $r_{3,5}$; $r_{4,9}$; $r_{5,10}$; $r_{6,5}$; $r_{7,1}$; $r_{8,6}$; $r_{9,9}$; $r_{10,2}$; $r_{11,2}$	66.14	1	0	$r_{1,10}$; $r_{2,8}$; $r_{3,9}$; $r_{4,9}$; $r_{5,7}$; $r_{6,8}$; $r_{7,2}$; $r_{8,3}$; $r_{9,6}$; $r_{10,4}$; $r_{11,3}$	71.98
15	2	7	1	$r_{1,12}$; $r_{2,15}$	10.75	4	0	$r_{1,1}$; $r_{2,12}$	11.95
	3	10	36	$r_{1,3}$; $r_{2,6}$; $r_{3,10}$	17.28	4	0	$r_{1,4}$; $r_{2,11}$; $r_{3,15}$	19.16
	4	9	69	$r_{1,4}$; $r_{2,13}$; $r_{3,6}$; $r_{4,1}$	23.75	4	0	$r_{1,7}$; $r_{2,12}$; $r_{3,14}$; $r_{4,3}$	25.49
	5	8	356	$r_{1,4}$; $\mathbf{r_{2,11}}$; $r_{3,1}$; $r_{4,13}$; $r_{5,11}$	30.72	4	4	$r_{1,9}$; $r_{2,8}$; $r_{3,8}$; $r_{4,14}$; $r_{5,5}$	32.79
	6	7	681	$r_{1,15}$; $r_{2,15}$; $r_{3,10}$; $r_{4,1}$; $r_{5,11}$; $r_{6,12}$	36.02	6	250	$r_{1,7}$; $r_{2,10}$; $r_{3,10}$; $r_{4,1}$; $r_{5,11}$; $r_{6,10}$	38.40
	7	7	1474	$r_{1,7}$; $r_{2,14}$; $r_{3,3}$; $r_{4,11}$; $r_{5,15}$; $r_{6,2}$; $r_{7,8}$	42.13	4	18	$r_{1,8}$; $r_{2,7}$; $r_{3,3}$; $r_{4,1}$; $r_{5,4}$; $r_{6,2}$; $r_{7,7}$	44.87
	*8	8	7264	$r_{1,7}$; $r_{2,13}$; $r_{3,4}$; $r_{4,2}$; $r_{5,9}$; $r_{6,2}$; $r_{7,5}$; $r_{8,1}$	47.12	3	23	$r_{1,3}$; $r_{2,11}$; $r_{3,3}$; $r_{4,13}$; $r_{5,12}$; $r_{6,13}$; $r_{7,11}$; $r_{8,15}$	50.97
20	2	14	8	$r_{1,8}$; $r_{2,3}$	11.07	3	1	$r_{1,12}$; $r_{2,10}$	12.67
	3	12	49	$r_{1,19}$; $r_{2,3}$; $r_{3,1}$	18.63	6	2	$r_{1,19}$; $r_{2,3}$; $r_{3,1}$	18.63
	4	12	1093	$\mathbf{r_{1,12}}$; $r_{2,19}$; $r_{3,6}$; $r_{4,14}$	24.36	8	53	$r_{1,10}$; $r_{2,19}$; $r_{3,6}$; $r_{4,14}$	24.88
	5	8	572	$r_{1,9}$; $r_{2,14}$; $r_{3,11}$; $r_{4,4}$; $r_{5,14}$	31.21	5	26	$r_{1,14}$; $r_{2,2}$; $r_{3,17}$; $r_{4,4}$; $r_{5,14}$	32.08
	6	11	7346	$r_{1,10}$; $r_{2,19}$; $r_{3,7}$; $r_{4,6}$; $r_{5,8}$; $r_{6,3}$	39.28	3	2	$r_{1,18}$; $r_{2,19}$; $r_{3,7}$; $r_{4,3}$; $r_{5,7}$; $r_{6,3}$	39.49
	*7	11	7477	$r_{1,8}$; $r_{2,6}$; $r_{3,12}$; $r_{4,10}$; $r_{5,7}$; $\mathbf{r_{6,2}}$; $r_{7,4}$	44.66	6	407	$r_{1,11}$; $r_{2,1}$; $r_{3,14}$; $r_{4,10}$; $r_{5,7}$; $r_{6,2}$; $r_{7,4}$	45.80
25	2	15	5	$r_{1,12}$; $r_{2,1}$	11.96	8	1	$r_{1,12}$; $r_{2,5}$	12.08
	3	14	116	$r_{1,15}$; $r_{2,9}$; $r_{3,2}$	18.74	7	5	$r_{1,1}$; $r_{2,25}$; $r_{3,13}$	20.24
	4	13	3244	$r_{1,20}$; $r_{2,24}$; $\mathbf{r_{3,13}}$; $r_{4,20}$	23.86	8	53	$r_{1,15}$; $r_{2,5}$; $r_{3,2}$; $r_{4,3}$	25.15
	5	12	5835	$r_{1,1}$; $r_{2,23}$; $r_{3,2}$; $r_{4,8}$; $r_{5,6}$	30.91	8	427	$r_{1,1}$; $r_{2,17}$; $r_{3,2}$; $r_{4,8}$; $r_{5,5}$	31.25
30	2	19	22	$r_{1,27}$; $r_{2,17}$	12.45	9	1	$r_{1,22}$; $r_{2,29}$	13.31
	3	18	623	$r_{1,2}$; $r_{2,24}$; $r_{3,23}$	17.62	11	75	$r_{1,11}$; $r_{2,19}$; $r_{3,27}$	18.60
	4	14	1805	$r_{1,30}$; $r_{2,26}$; $r_{3,13}$; $r_{4,26}$	25.38	9	68	$r_{1,30}$; $r_{2,6}$; $r_{3,11}$; $r_{4,22}$	25.46
	*5	17	7476	$r_{1,23}$; $r_{2,18}$; $r_{3,10}$; $r_{4,22}$; $\mathbf{r_{5,25}}$	29.95	12	3200	$r_{1,14}$; $r_{2,10}$; $r_{3,15}$; $r_{4,3}$; $r_{5,25}$	30.97
35	2	20	23	$r_{1,24}$; $r_{2,33}$	11.98	11	1	$r_{1,5}$; $r_{2,15}$	12.07
	3	22	685	$r_{1,34}$; $r_{2,34}$; $r_{3,27}$	19.04	9	12	$r_{1,34}$; $r_{2,23}$; $r_{3,19}$	20.36
	4	17	7219	$r_{1,24}$; $r_{2,25}$; $r_{3,28}$; $r_{4,4}$	25.31	15	1692	$r_{1,11}$; $r_{2,10}$; $r_{3,5}$; $r_{4,2}$	26.21
40	2	23	36	$r_{1,32}$; $r_{2,10}$	11.28	10	2	$r_{1,28}$; $r_{2,19}$	12.13
	*3	23	7565	$r_{1,17}$; $r_{2,8}$; $r_{3,3}$	18.76	15	185	$r_{1,27}$; $r_{2,34}$; $r_{3,17}$	19.92
	*4	23	7675	$r_{1,10}$; $r_{2,17}$; $r_{3,24}$; $r_{4,9}$	25.36	11	799	$r_{1,2}$; $r_{2,13}$; $r_{3,2}$; $r_{4,2}$	26.03
45	2	27	651	$r_{1,28}$; $r_{2,16}$	12.16	11	3	$r_{1,35}$; $r_{2,2}$	12.26
	3	27	1704	$r_{1,22}$; $\mathbf{r_{2,31}}$; $r_{3,22}$	18.22	14	133	$r_{1,22}$; $r_{2,35}$; $r_{3,28}$	20.04
	*4	22	7319	$r_{1,20}$; $r_{2,38}$; $r_{3,41}$; $r_{4,5}$	25.89	14	1167	$r_{1,20}$; $r_{2,39}$; $r_{3,41}$; $r_{4,5}$	26.65
50	2	31	69	$r_{1,33}$; $r_{2,42}$	11.32	14	5	$r_{1,39}$; $r_{2,8}$	12.63
	*3	28	7262	$r_{1,15}$; $r_{2,41}$; $r_{3,11}$	18.91	19	1590	$r_{1,1}$; $r_{2,48}$; $r_{3,23}$	18.94
	4	24	6813	$r_{1,50}$; $r_{2,38}$; $r_{3,36}$; $r_{4,2}$	23.21	14	2600	$r_{1,22}$; $r_{2,41}$; $r_{3,37}$; $r_{4,12}$	25.49

Legend: ***Xc***: Nº of candidate resources; ***n***: Nº of tasks; ***k***: Nº of resources pre-selected; ***t***: Simulation time; **Final System**: System of selected resources; **System Value**: total value of the final system; r_{ij}: Resource *j* for task *i*; $\mathbf{r_{ij}}$: Resources not obtaining positive values in the 3 systems of level 2; * Exceeding time limit.

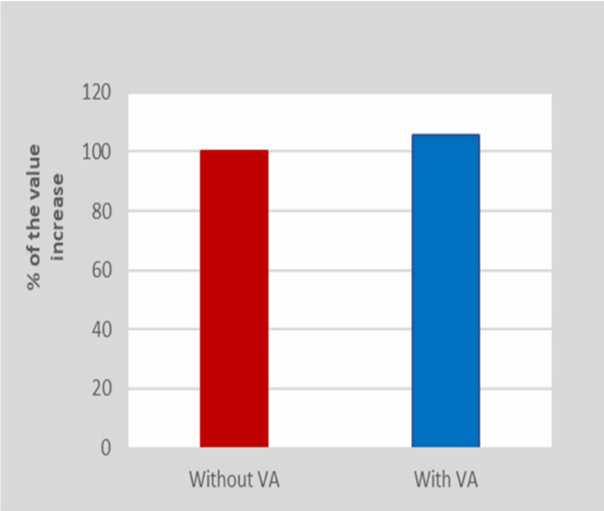

Figure 6. Average increment of the value of the final resources systems.

Nevertheless, still more important than the previous analysis, the computational results also show that VA provides systems ensuring that all the selected candi–dates obtain positive value in the level 2 systems, but, this does not occur without VA. In Table 3 the final systems of resources incorporating resources with the format $\mathbf{r_{ij}}$, means that these resources did not obtained positive value.

Almost 20% of the resources systems, obtained without VA, fall in this situation, as is shown in Figure 7. However, it is of utmost importance for A/V E project promoters to be able to ensure that every one of the resources has positive value either in pre-selection systems or mainly in the final system resources. If one of the selected resources cannot achieve this positive required value, it can compromise all the entire system of resources. It means that the risk of the A/V E consistency is higher and VA, therefore, can play the fundamental role of guaranteeing confidence in the final resources system in order to obtain the successful integration of all the selected resources.

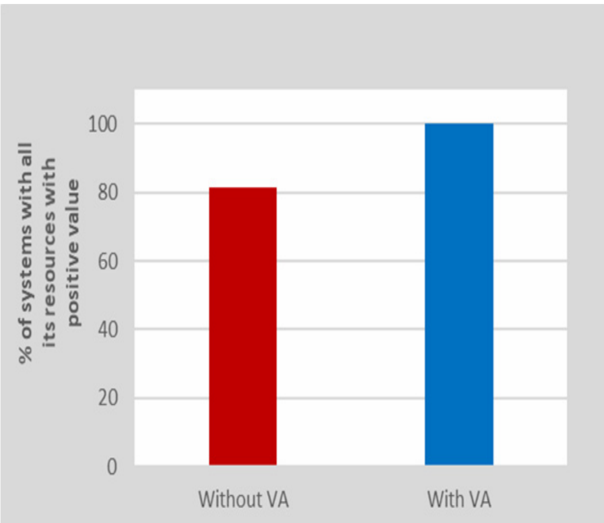

Figure 7. Final resources systems with its all resources with positive values.

Moreover, table 3 demonstrates that the SRS processing time (time spent for pre- and final selection) is lower with VA than without it. In terms of percen–tage, considering that the time spent without VA for all the simulations represents 100%, the same value with VA has the average value of 7.5% (see Figure 8). It represents a strong average reduction of the time spent in 92.5%, between a range of a minimal of 57% and a maximum of 100%. Leading with a faster selection process, with obvi–ous time savings and associated cost reductions, is expect to achieve higher reconfiguration agility of an A/V E.

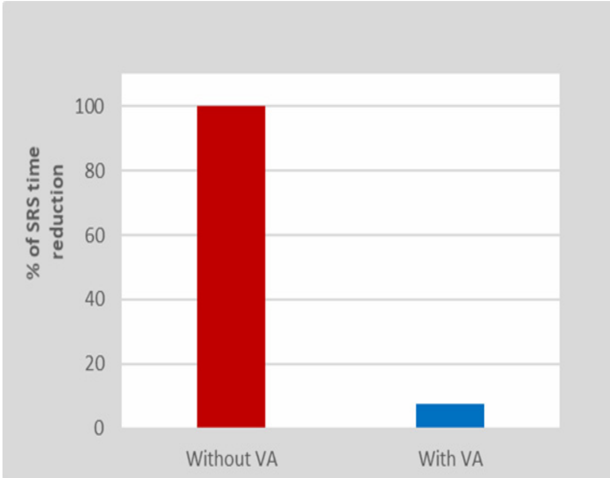

Figure 8. Average reduction of the SRS time spent.

Table 4. Average k_w and k_v for each Xc.

Xc	10	15	20	25	30	35	40	45	50
Average of k_w	5.3	8.0	11.3	13.5	17.0	19.7	23.0	25.3	27.7
Average of k_v	2.0	4.1	5.2	7.8	10.3	11.7	12.0	13.0	15.7

The time spent reduction is aligned with the reduc–tion of complexity measure when is incorporated VA, as was referred in Section 3 as expected. In order to quantify this reduction, with the k values from table 3, were calculated the average k_w and k_v for each Xc. It means nine averages for each one, as we can see in Table 4.

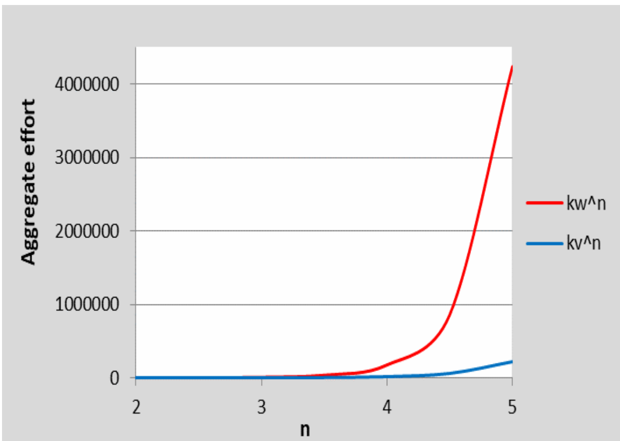

Figure 9. Aggregate effort without VA (k_w^n) and with VA (k_v^n).

From Table 4, for each *Xc* we see that $k_w > k_v$, which validates our hypothesis that: $O(k_w^n) > O(k_v^n)$, i.e., the inclusion of VA reduces the complexity of SRS process

To obtain a global quantification of the effort with the computational results we defined the measure we call it "Aggregate effort" defined as:

$$Aggregate\ effort = \sum k_i^n \quad (10)$$

Then, for both cases, using the values from the Table 4, we have the following expressions for the Aggregate efforts:

$$k_w^n = 5.3^n+8.0^n+11.3^n+13.5^n+17.0^n+19.7^n+23.0^n+ 25.3^n+27.7^n$$

$$k_v^n = 2.0^n+4.1^n+5.2^n+7.8^n+10.3^n+11.7^n+12.0^n+ 13.0^n+15.7^n$$

The representation of the aggregate efforts in Figure 9 gives a vision of the effort reduction when the integration of VA is considered.

The last two results analyses, associated to the figures 8 and 9, confirm our thesis that VA reduces the complexity of the SRS process. Furthermore, the first two analyses, associated to the figures 6 and 7, ensure that this complexity reduction is achieved without loss of quality/value grade, even by the contrary, the final system of resources increased his quality/value grade with VA.

6. CONCLUSIONS

This work identified a lack of any explicit and/or formal treatment of the pre-selection process in the literature and the gaps of SRS models. In short, because the SRS is a complex problem, the models should assure more effectiveness and efficiency, i.e., with less complexity and assuring the effectiveness of the solution. Thus, was created a SRS model with the integration of VA, which covers the resource pre-selection in A/V E. Three main pre-selection phases were defined (bid solicitation, reception, and analysis/evaluation); new pre-selection requisite systems (quality, financial, and synergies) were developed and the VA steps to be incorporated in resource pre-selection phase were explained.

Through the computational results was measured the performance of the integration of VA in the SRS process for the DSMWO and verified that: VA in pre-selection resulted a higher value (plus 5.5% on average) in the final resources system, independently of the number of TP tasks, the number of candidate resources or the quantification of the systems' weights and their associated requisites; none of the candidate resources selected fails to obtain a positive value (100% with VA against 81% without) in the final system of resources; VA also shown to lead to greater time efficiency which is reflected in the time spent (less 92.5% on average) for SRS process; the decrease in time spent and the inherent decrease in the number of resources pre-selected, lead to a reduction in the complexity.

As a main conclusion, VA reduces the complexity of the SRS process, even ensuring that the final system of resources achieve higher quality/value grade. These results are very encouraging for upcoming A/V E design needs (more candidate resources) with the increasing of interconnectivity among the enterprises, achieved by the I4.0 tools implementation.

Further research work should attend the SRS with VA for the Dependent or Integral Selection Method with Pre-selection of Transport Resources, the most complex selection process.

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АНАЛИЗА ВРЕДНОСТИ КАО МЕХАНИЗАМ ЗА РЕДУКОВАЊЕ КОМПЛЕКСНОСТИ ИЗБОРА СИСТЕМА РЕСУРСА ЗА АГИЛНА/ВИРТУЕЛНА ПРЕДУЗЕЋА У КОНТЕКСТУ ИНДУСТРИЈЕ 4.0

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Избор система ресурса (ИСР) важан је елемент у интеграцији/пројекту агилних/виртуелних предузећа (А/В П) јер њихове перформансе зависе од овог избора, па чак и од њиховог стварања. Међутим, овај проблем и даље остаје тежак јер и даље пред–ставља врло сложен и неизвестан проблем. У раду се предлаже да коришћење Анализе Вредности (АВ) у фази предизбора ресурса представља значајно по–бољшање процеса ИСР. Тренутна литература се не бави формално фазом предселекције и ниједан од модела избора ресурса не укључује вредност ре–сурса и њене последице у оквиру комплексности процеса избора. При томе, наш развијени модел са АВ представља иновативан приступ ка већој одр–живости у конфигурацији А/В П у контексту Ин–дустрије 4.0, где се очекује масовна међусобна повезаност предузећа и последично повећање комп–лексности процеса избора. Након конструисања инструмента за демонстрацију за скуп формулација проблема, у овом раду је рачунским путем верифи–

кована хипотеза о предностима примене АВ на процес ИСР: АВ смањује комплексност процеса ИСР, и додатно обезбеђујући да коначни систем ресурса постиже вишу оцену квалитета/вредности.