MANUFACTURING MULTI-AGENT SYSTEM WITH BIO-INSPIRED TECHNIQUES: CODESA-PRIME

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This paper deals with the multi-agent manufacturing system with application of bio-inspired techniques and new approaches to the development trends of advanced industrial engineering (AIE) in energy efficient manufacturing. This integration represents a sustainable development so that more effective use of natural and energy resources is achieved and energy costs are reduced. The new solution of reference model for control and coordination decentralized systems – CODESA is proposed. Centralized architecture suffers from various problems, such as rigidity, scalability, low fault-tolerance or very limited ability for flexibility, agility and productivity. Prime is concrete application of CODESA in manufacturing domain. Its concrete application, CODESA-Prime, was verified in simulation logistics multi-agent system.

KEYWORDS
multi-agent system, sustainable production
advanced industrial engineering, biologically inspired techniques
CODESA-Prime

1. INTRODUCTION

In the last two decades, the attention of experts is focused especially to a holonic and multi-agent manufacturing systems [Wooldridge 1995]. Multi-agent systems (MAS) have been applied to areas such as control, production planning, scheduling, resource allocation, vehicle routing, etc. [Weiser 1991]. The advantage of such heterarchical architecture is the absence of superior unit, which in practice can be a single point of failure in the system. Individual agents communicate directly with each other. This allows scalability (no need to shut down production system in order to add or remove resources), increases flexibility, modularity and agility. The multi-agent system itself provides high fault-tolerance. A simple implementation of the control software ensures low maintenance needs and transparency of the source code. The main disadvantage of heterarchical architecture is the phenomenon coming from emergent behaviour [Thomas 2012].

The undesirable characteristics of emergence are, for example, **the problem to achieve optimization and impossibility to predict future states of the system.** The solution seems to be used the semi-heterarchical architecture, introducing hierarchies into the heterarchies [Varvara 2014], [Barbosa 2015]. This paper is structured in the form of five main sections. The first section discusses the introduction and overview of agent and service systems in industrial automation in next generation manufacturing systems. Authors emphasize the multi-agent manufacturing system with application of biologically inspired techniques. The second section outlines the proposed solution and definition of the new reference model for control and coordination decentralized systems – *CODESA* that can be applied to multiple domains such as manufacturing systems, transportation, healthcare, military, power grids, etc. However, the full review of this approach in merging these emerging technologies is beyond the scope of this paper. The following third section covers the description of technological structure CODESA-*Prime* designed for manufacturing domain and its simulations for AGV systems. The fourth section discusses in turn the key priorities for information and communication technologies enabled energy efficiency in manufacturing. There is also the methodology for reducing energy intensity of production processes. The main findings are then summarized in the conclusion.

1.1 Overview of Agent and Service Systems in Industrial Automation

The global market are imposing strong changing conditions for companies running their businesses, something comprising complex and large scale systems [Leitao 2013a]. Agent systems were introduced in automation and manufacturing when there was the vision of having distributable software components to resolve local tasks, comparable to the heterogeneous nature of the physical domain. Existing models of production, such as Flexible Manufacturing Systems (FMS) [Tombak 1988], Reconfigurable Manufacturing Systems (RMS) [Mehrabi 2000] and Collaborative Manufacturing Management (CMM) [Gorbach 2002], are a basis for the application of multi-agent systems to solve and optimize the problems of production, due to the increase of introduced complexity. [Tnazefti-Kerkeni 2003] Among the several publications reporting the application of MAS in automation and production systems, the reader can consult the reference [Marik 2005] to retrieve more information on this topic [Mendes 2009]. The benefits of agent-based industrial systems are robustness, scalability, reconfigurability and productivity, all ofwhich translate to a greater competitive advantage [Lietao 2013a]. Multi-agents systems is pointed out as a suitable approach to address this challenge by offering an alternative way to design control systems, based on the decentralization of control functions over distributed autonomous and cooperative entities. However, in spite of their enormous potential, they usually lack some aspects related to interoperability, optimization in decentralized structures and truly self-adaptation [Leitao 2013b]. A solid understanding of the technical and economic factors that characterize a real-time application helps to interpret the demands that the system designer must cope with [Kopetz 2011].

2. DEVELOPING THE DESIGN OF THE ARCHITECTURE

The authors have proposed the technological structure to eliminate these disadvantages and to add more useful features for control distributed systems. This new reference model for control and coordinating decentralized systems is named *CODESA* and is shown in Fig. 1. Application of this technological structure is possible in domains where control of non-linear, heterarchical, large-scale systems in dynamic, heterogeneous and unpredictable environment is needed. The main characteristics of *CODESA* are:

- fault-tolerance (MAS, Swarm Intelligence, etc.),
- high level of modularity and reconfigurability (MAS, Service-oriented Architecture – SOA, Internet of Things – IoT),
- enhanced interoperability (Domain ontology, SOA),
- fast processing and storing large amounts of data (CLOUD, IoT),

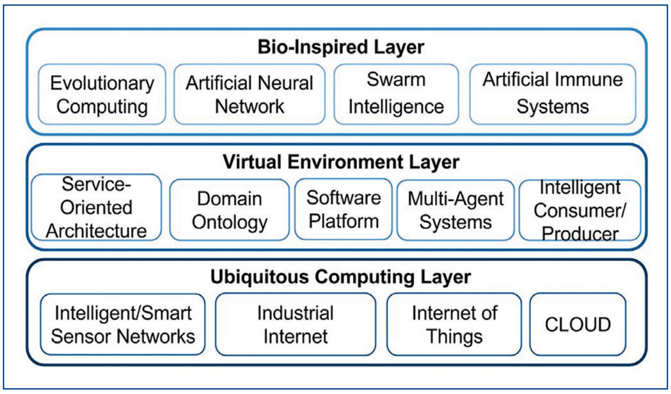

Figure 1. New reference technological structure CODESA

– autonomous and intelligent behavior (MAS, Swarm Intelligence),
– the ability to predict future conditions, and proactively react (Swarm Intelligence),
– adaptation of system and techniques of Bionic layer (Evolutionary Computing),
– use of dual communication: (direct – modified CNP protocol and indirect – based on pheromones in a virtual environment (Software Platform, Swarm Intelligence), etc.

Full description of merging described technologies is beyond the scope of this paper. This technological structure consists of three layers:
– Ubiquitous Computing Layer,
– Virtual Environment Layer,
– Bio-Inspired Layer.

2.1 Ubiquitous Computing Layer
Ubiquitous environment is the concept of software engineering and computer science, where computing can be done everywhere and on everything. The term potential of ubiquitous computing means everywhere-presence information technology and computing power that is present in everyday objects that we use. The idea of integrating computers seamlessly into the world at large runs counter to a number of present-day trends. "Ubiquitous computing" in this context does not just mean computers that can be carried to the beach, jungle or airport. Even the most powerful notebook computer, with access to a worldwide information network, still focuses attention on a single box. This potential of ubiquitous computing can be applied to whole areas of industrial production and private daily activities. This situation is made possible thanks to technological advances, availability, small size and price of computing devices. This layer provides industrial ubiquitous internet of things with a unique identity, communicating in real time with the possibility of processing and storing data on the side of device or on the side of high-performance-computing system – the CLOUD.

2.2 Virtual Environment Layer
Virtual Environment Layer provides virtual entities, which can reflect the entities in real world. These entities are autonomous, intelligent and capable of decision-making, communicating with each other using the domain ontology and integrating sub-systems and systems into self-organizational structure. Overview of the ontologies and their suitability for process automation domain and its subdomains [Lepuschitz 2015] evaloraboted Lepuschitz. Virtual Environment layer provides a picture of the real factory in a virtual environment. Agents can be located in the Software Platform or can be merged with devices (resources, products, etc.).

2.3 Bio-Inspired Layer
Bio-Inspired Layer represents a set of biologically inspired techniques and technologies. Swarm Intelligence [Van Dyke Parunak 2008] can be used to eliminate some of the previously mentioned negative characteristics (derived from heterarchical architectures, multi-agent systems, lack of adaptability, etc.), using indirect pheromone-based communication.

2.4 Application
As mentioned, the application of technological structure of *CODESA* is possible in areas where it is necessary to control non-linear, heterarchical, large-scale systems in dynamic, heterogeneous and unpredictable environment. Possible application domains are:
– manufacturing systems: ***CODESA-Prime*** is compatible with Industry 4.0,
– transportation,
– agriculture,
– healthcare,
– military,
– power grids, etc.

3. ANALYSIS OF *CODESA-PRIME*
With technological structure designed for manufacturing domain CODESA-*Prime*, it is possible to control, plan, schedule, manufacturing, optimize processes, route product and mobile agents, manage inventory, create prediction, etc.

3.1 CODESA-Prime: Virtual Factory Layer
In *CODESA-Prime* is Virtual environment layer called Virtual factory layer. Three main types of agents characterize *Prime*:
– Intelligent Order Agent (IOA),
– Intelligent Product Agent (IPA),
– Intelligent Resource Agent (IRA).

These three types of agents form the Holon Smart Factory. The relationship is shown in Fig. 2.

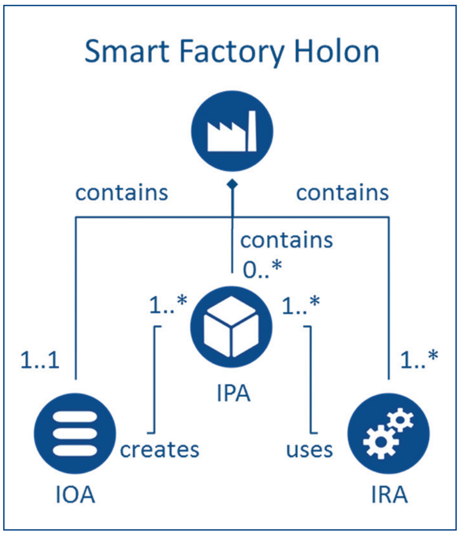

Figure 2. The relationship between the main types of agents in the architecture CODESA-PRIME

The properties are defined by merging technologies used in CODESA-*Prime* structure (Fig. 3). Agents in this layer can communicate indirectly, through pheromone-based approach. Decision making in this layer is based on the Contract-New protocol (CNP). Smart Factory Holon stores information s of Intelligent Resources Agents (IRA) about services offered by them.

In this way list of Holon´s services is created. By merging agents and holons into corresponding holon, layers of services can be created, which is compliant with SOA and at the same time with philosophy of the holonic systems.

However, such encapsulation of the services must be dynamic. Ella Software Platform provides services, such as the virtual environment that is the model (reflection) of the real factory, in which the agents can travel through, base for dual communication, and meta-schema through which ant-agents can move and indirectly communicate using pheromones. The simple illustration of the *CODESA-Prime* is shown in Fig. 4.

Intelligent Order Agent (IOA) receives from user or upper control layer an instruction to produce the product. If the product consists of other parts (other IPAs), IOA can use a simple algorithms for optimizing the production processes [Hsieh 2009].

Then it creates and initializes the Intelligent Product Agent (IPA), which downloads information about its manufacturing process (which may be checked after every manufacturing operation and change product properties during its manufacturing) from CLOUD.

IPA represents "voice of the customer" and exists during all phases of the product´s life cycle [Trentesaux 2013]. Subsequently IPA negotiates and allocates services offered by Intelligent Resource Agent (IRA). IPA

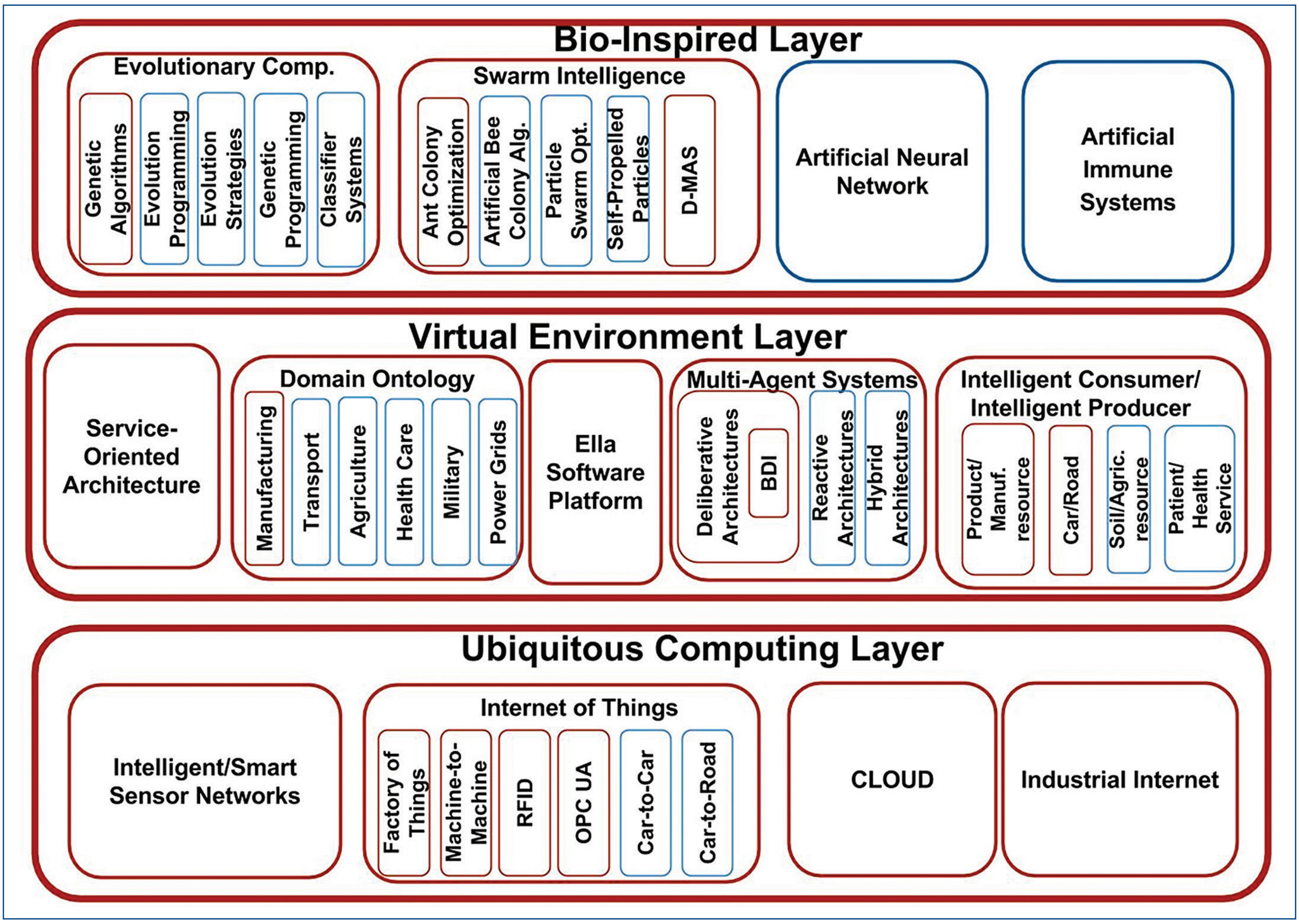

Figure 3. Prime – concrete application of CODESA in manufacturing domain (used technologies and techniques in red)

informs its status to IOA. IOA communicates this information to the user or upper control layer.

Codesa-*Prime* **has been tested in simulations for Automated Guided Vehicle systems (AGV systems)**, which have been tested basic aspects of multi-agent systems **in Ella Software Platform** (Fig. 5).

Each AGV system is represented by an Intelligent Resource Agent and presents its service to Intelligent Product Agent. Agent AGV system reserves a different path segments, which are also represented by the agent (Intelligent Agent Segment).

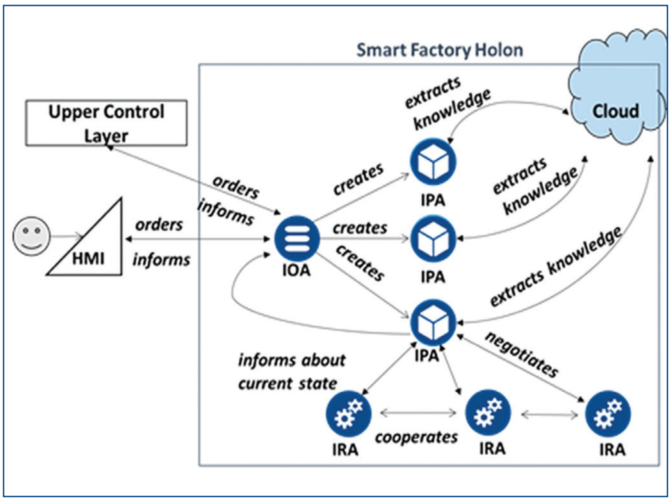

Figure 4. CODESA-Prime: Simplified illustration of functions

The connection of scheduling capabilities for logistics systems and routing through production optimize the use of logistical resources, as well as individual road segments. Simulation has been verified that the Codesa-*Prime* has proved for logistics systems.

3.2 CODESA-Prime: Bio-Inspired Layer

Agents can create (cast) lightweight agents, also called ants or ant-agents, and delegate them across the virtual environment that can be represented as graph. These lightweight agents have a short life (defined by agents) and can perform only certain specific activities.

This means that these ant-agents are computationally efficient. They can deposit, locate, observe and modify digital pheromones in the graph (virtual environment). These digital pheromones represent indirect communication.

Pheromon-based communication is suitable to control social and temporal myopic behaviour that is needed to handle uncertainties in manufacturing processes [Rey 2013].

As mentioned, *CODESA* uses dual communication. Indirect communication belonging to Bio-Inspired Layer has the following properties:

- It is inspired by food foraging in ant colonies.
- Replaces direct communication.
- Communication is done through virtual environments (represented by weighted graphs) by depositing, observing and modifying the pheromones.
- Delegated, lightweight agents called ants deposit pheromones in virtual environments. These ants are casted periodically by main agents (IPA, IRA).
- Pheromones decay in time.

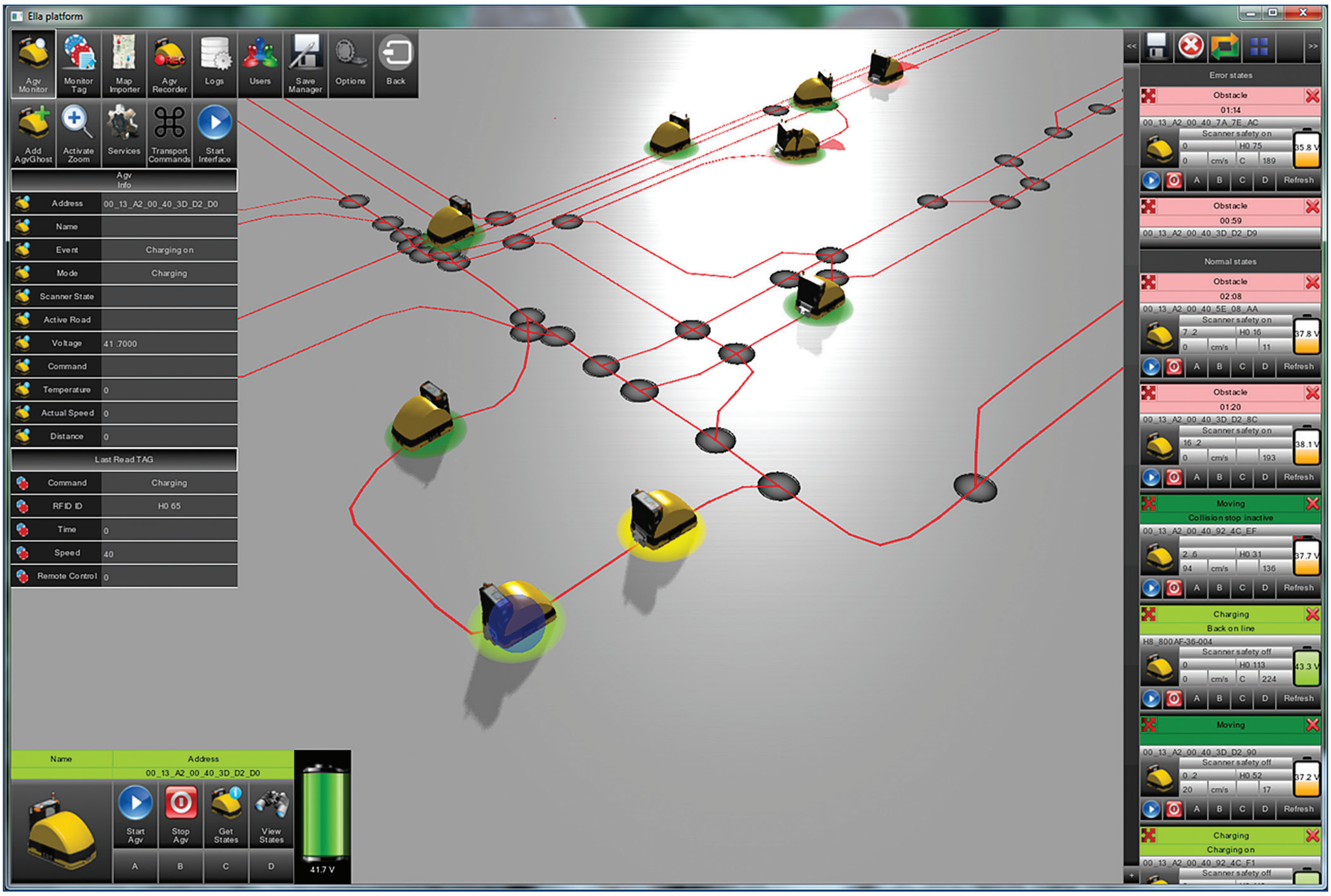

Figure 5. Testing of CODESA-Prime for AGV system in Ella Software

- In graph (meta-scheme) are relations between individual main agents (or theirs avatars) are represented by graph´s edges, meta-schema (Fig. 6).
- Ants deposit pheromones at graph´s vertices.
- Each ant has temporary memory, limited processing power and limited life.

There are three types of ant-agent colonies [Van Dyke Parunak 2008]:

- Exploration ants that are casted by Intelligent Products Agents search the graph in order to find the needed services presented by Intelligent Resource Agents and inform the IPA about possible routes and their costs. They ask the question "what-if". Agent decides what route will choose.
- Intention ants, which are also casted by Intelligent Products Agents, have the task to allocate ("book") the resources.
- Intelligent Resource Agents presents its services through Feasibility ants.

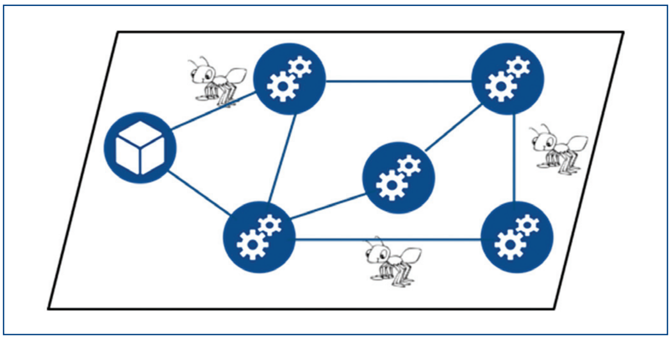

Figure 6. The example of meta-schema, agents casts ants-agents that travel along the edges of the graph and deposit pheromones at vertices

The use of **indirect** communication in *CODESA-Prime* is used at:

- Routing intelligent product through factory´s services and allocation of the resources.
- Routing logistics systems through a network of paths.

The lists of the selected properties of agents are described in Table 1.

The target cost of route of services in routing intelligent products and allocation of production capacities based on weights of the following priorities:

- *w_time* is weight of time,
- *w_qos* is weight of quality of service,
- *w_envimp* is weight of environment impact.

Target cost of path in routing the logistics resources through the network of paths is based on weights of the following priorities:

- *w_dist* is weight of distance,
- *w_time* is weight of time,
- *w_qos* is weight of quality of service,
- *w_envimp is* weight of environment impact.

Route through the services need to be found first. Then the route through the network of paths to services is computed. Algorithm finds target route of services defined by mentioned priorities.

for each *route in Routes* ***do***
for each *service in route.Services* ***do***
costOfTime(route) = costOfTime(route) + service.cost.time
costOfQOS(route) = costOfQOS(route) + service.cost.qos
costOfEnvimp(route) = costOfEnvimp(route) + service.cost.envimp
end for

(IOA)	(IPA)	(IRA)
Software form	Software and/or physical form	Software and/or physical form
– takes orders from the HMI or upper control layer, – has capability to process different data formats, – creates and initializes IPAs, – informs about the current status of IPAs, – if there are too many IPAs to create, IOA can use for optimizing the production [Hsieh 2009], – before creating the product detects whether the services available to the processed product, – if several separate holon that make up the operation, it is possible that the number of AIO creates and initializes agents.	– represents product instance (workpiece) – can store or remove storage from their physical part, in case of unsuccessful machining, – possesses a unique identification, – deploys a language to display its features, production requirements, repeatedly, etc. – is capable of participating in or making decisions relevant to own destiny, – **can be eco-friendly,** – **supports cleantech, creating eco-innovation,** – **monitor energy consumption and propose corrective action,** – can be driven by priorities such as: distance, time, quality, environment impact, – exists during all phases of the product´s life cycle – has beliefs, desires, and intentions.	– represents manuf. or logistics resource, – some services can be composed by other services, creating a levelled structure of services, – repeatedly and transparently presents services that is able to provide, – contains schedule and can inform others about it, – gather information about services presented in virtual environment. – cooperates with other IRAs

Table 1. Selected agent´s properties characterizing CODESA-PRIME

```
allCostsTime(route) = costOfTime(route)
allCostsQOS(route) = costOfQOS(route)
allCostsEnvimp(route) = costOfEnvimp(route)
end for
maxTimeCost = findMaxCost(allCostsTime)
maxQOSCost =findMaxCost(allCostsQOS)
maxEnvimpCost =findMaxCost(allCostsEnvimp)
for each route in Routes do
timeCost(route) = (allCostsTime (route) * w_time) / maxTimeCost
QOSCost(route) = (allCostsQOS (route) * w_qos / maxQOSCost
envimpCost(route) = (allCostsEnvimp (route) * w_envimp) /
maxEnvimpCost
totalCostOfServices(route)= timeCost(route) + QOSCost(route) +
envimpCost(route)
end for
targetCostOfSevices, newServiceRoute =
findMinCostAndSeviceRoute(totalCostOfServices)
```

This part of algorithm finds target cost and target path through the network of paths to services.

```
for each path in Paths do
for each segment in path.Segments do
costOfDistance(path) = costOfDistance(path) + segment.cost.distance
costOfTime(path) = costOfTime(path) + segment.cost.time
costOfQOS(path) = costOfQOS(path) + segment.cost.qos
costOfEnvimp(path) = costOfEnvimp(path) + segment.cost.envimp
end for
allCostsDistance(path) = costOfDistance(path)
allCostsTime(path) = costOfTime(path)
allCostsQOS(path) = costOfQOS(path)
allCostsEnvimp(path) = costOfEnvimp(path)
end for
maxDistanceCost = findMaxCost(allCostsDistance)
maxTimeCost = findMaxCost(allCostsTime)
maxQOSCost =findMaxCost(allCostsQOS)
maxEnvimpCost =findMaxCost(allCostsEnvimp)
for each route in Routes do
distanceCost(path) = (allCostsDistance(path) * w_dist) /
maxDistanceCost
timeCost(path) = (allCostsTime(path) * w_time) / maxTimeCost
QOSCost(path) = (allCostsQOS(path) * w_qos / maxQOSCost
envimpCost(path) = (allCostsEnvimp (path) * w_envimp) /
maxEnvimpCost
allCostsOfServices(path)= timeCost(path) + QOSCost(path) +
envimpCost(path)
end for
targetCostOfPath, newPathRoute =
findMinCostAndPathRoute(allCostsOfServices)
```

Total target cost consists of two parts:

```
totalTargetCost = targetCostOfSevices + targetCostOfPath

//intertiaParameter ∈ R, 0 ≤ intertiaParameter ≤ 1
//inertiaParameter says how much better must be new solution

if (totalTargetCost*inertiaParamter) > actualTotalTargetCost then
actualTargetRoute = (newServiceRoute, newPathRoute)
actualTotalTargetCost = totalTargetCost
end if
```

Indirect communication is compliant with BDI human-based decision-making model. Pheromones in virtual environment represent agent´s beliefs. Booking represents its intentions. Final state of product represents its desire.

The advantages of pheromone communication over Contract Net Protocol:
- CNP allocates resources sequentially; pheromone communication can allocate multiple sources concurrently.
- Deadlines make CNP inflexible.
- Complex communication is simplified.

Advantages of the pheromone communication control:
- control and coordination of decentralized systems,
- ability to predict the future states,
- short-term forecasting allows predictive control,
- ability of the system to proactive respond,
- control of large-scale systems in a dynamic, complex, heterogeneous and unpredictable environment,
- lightweight ants agents are computationally inexpensive,
- self-organization, self-optimization and self-repair system.

Disadvantages of pheromone communication:
- Common virtual environment can be a single point of failure of the entire system – for this reason, dual communication and replication of virtual environment is needed.
- Many adjustable parameters (routing product and logistics systems).

Related to this point is:
- rate of casting colonies,
- number of ant-agents released in one colony,
- rate of pheromone decaying,
- initial intensity of pheromone,
- renewed intensity of pheromone,
- inertia of the system (how much lower must be cost of the new alternative route than actual),
- priority in choosing directions: time, distance, price, environment impact (can be set by users),

– cloning ant-agents on each vertices (yes/no),
– maximum number of vertices travelled by one ant-agent (number of hops),
– exploration colonies inform about possible future booking (yes/no),
– need to vary the intensity and scope of pheromones that present services of Intelligent Resources Agent (yes/no),
– reliable prediction horizon,
– the various colonies publish various services/one colony publish one service (yes/no),
– required computing performance, etc.

Solution can be to adapt the system using genetic algorithms, and to cast test ant-agent colonies with different behaviours (or personalities). Chromosome would be formed by the mentioned adjustable parameters. Colonies would be evaluated by their fitness at the end of each cycle. The fittest colonies can be reproduced – **truly adaptive system**.

Many enterprises, especially manufacturing, integrate eco-innovations. It turned out that that integration creates conditions for sustainable development. They reduced environmental impacts. This efficient use of natural resources often markedly reduces production costs. The design of *CODESA-Prime* supports these eco-innovations and sustainable manufacturing.

Manufacturing enterprise based on that approach are trying to use (if permitted by the conditions of production) energy efficient systems. The philosophy and methodology of these systems are engaged in the following section.

4. INFORMATION AND COMMUNICATION TECHNOLOGY ENABLED ENERGY EFFICIENCY IN MANUFACTURING

The changing customer demands put great emphasis on the flexibility of production, innovation and flexibility to respond to changes [Dulina 2014].

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behavior, which result in turbulences [Gregor 2009]. Reducing energy waste in manufacturing enterprises helps reduce manufacturing costs, and helps keep our industries competitive [Staszewska 2013].

The recognition that sustainable natural eco-systems result from cyclic functioning led to the concept of sustainable manufacturing being proposed [Ehrenfeld 2014]. Unquestionably, IMS technologies, architectures, management and control approaches will be useful for sustainable industries [Pannequin 2009].

Future miniaturization of dimensions will focus more and more on increasing a product's sophistication, performance, and market penetration [Krajcovic 2013].

Industrial requirements have clearly evolved from the traditional performance criteria, described in terms of static optimality or near-optimality, towards new performance criteria, described in terms of reactivity, adaptability and visibility. A growing number of industrialists now want control systems that provide satisfactory, adaptable and robust solutions rather than optimal solutions that require several hard assumptions to be met [Thomas 2013], [Trentesaux 2012].

The main task of manufacturing system reconfigurability lies in hardware and software components changing [Micieta 2015]. Reconfigurable manufacturing systems are proposed as a solution to unpredictable fluctuations in market demand and market turbulence [Westkamper 2009].

Realising cost-effective energy efficiency potentials will be beneficial not only for individual energy consumers, but also for the economy as a whole [Micietova 2014]. Tomorrow's energy efficient manufacturing will require additional processing power at all levels of its infrastructure [Rakyta 2014].

The biggest savings is generally from the avoided new materials production, but the difference between new manufacturing and remanufacturing can also be significant [Koren 2010].

To gather a better understanding of the current state of research and gap analysis of research and technology development activities specific to information and communication technology usage for energy efficiency in manufacturing, the methodology for reducing the energy intensity is proposed.

The verification of the methodology is realized in rubber industry. Energy efficiency in manufacturing can be improved by a wide variety of technical actions including:
– Maintaining, refurbishing and returning equipment to counter natural efficiency degradation and to reflect shifts in process parameters.
– Retrofitting, replacing and retiring disused machine and equipment, process lines and facilities to new and state of art technologies.
– Using heat management to decrease heat loss and waste energy by, for example: proper use of insulation; utilization of exhausted heat and materials from one to other processes.
– Improving process control, for better energy and materials efficiency and general process productivity.
– Streamlining processes-eliminating processing steps and using new production concepts.
– Re-using and recycling products and materials.
– Increasing process productivity.
– Decreasing product rejects rates and increasing materials yields [Darabnia 2013].

Policy facilitates those technical efforts. A policy of energy efficiency should also be able to exploit the potential in various fields, in particular in the industrial sector where efficiency means greater competitiveness and thus trigger a virtuous circle for the country's economy.

The successful use of policy for energy efficiency improvement depends on how policy can finally give incentives for each possible technical improvement, directly or indirectly, to industry sector.

4.1 Reduction the energy intensity of production processes

Before an implementation of the methodology of improving energy efficiency in production processes need to be addressed by including achieving energy efficiency in business strategy – management decision, that this area will be developed and will be included in the strategic objectives of enterprise, because energy must be regarded as valuable resources needed for business.

All enterprises can save energy by using appropriate principles and techniques of industrial engineering, which are used in business for key resources such as raw materials and work practices [Thiede 2012].

This management must include full managerial responsibility for the use of energy. Management of energy consumption and eliminate wasted loads then brings cumulative savings. The first part deals with the methodology of the evaluation process energy efficiency of production processes. This includes:

1. **step: energy planning of measurement of energy consumption**, which is the basis for energy management in production processes for decision-making of measures for improvement and optimization of increasing energy efficiency.

2. **step: implementation and control of increasing energy efficiency in production processes**, the proposal of factors and indicators of energy efficiency, analysis of energy cost reduction.

3. **step: the need for subsequent re-configuration management system**, in which will be realized by monitoring energy consumption and propose corrective action (***CODESA-Prime*****: Intelligent Product Agent**).

4. **step: checking and improvement,** management review for continual improvement and controlling.

The second part of the methodology involves enabling and supporting energy efficiency of production processes. In addition, information and communication technologies (ICTs) and standardization will play an

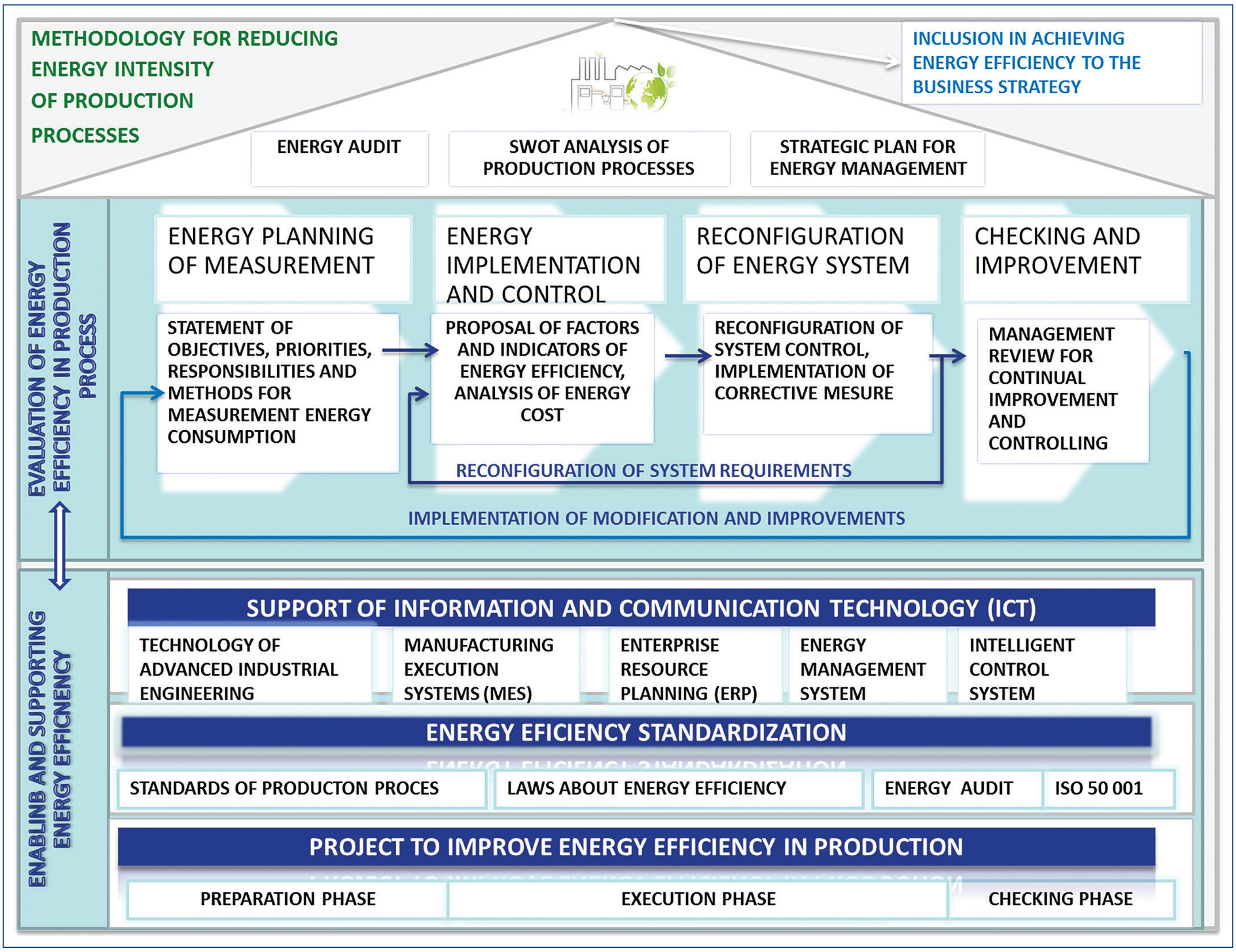

Figure 7. Methodology for reducing the energy intensity of production processes

important role and are essential in creating energy-efficient production. For example, ISO 50 001:2011.

The purpose of this international standard is to enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption [ISO 50001 2011].

Digitizing, modeling, simulation and emulation are used to understanding of comprehensive manufacturing processes and creation of new knowledge, which is used for optimization of real production systems [Gregor 2015].

Depending on the model, especially lightweight materials are used for the individual parts, for example, aluminum in the front end and chassis [Kohar 2014].

Methodology for improving energy efficiency of production processes consists of two mentioned basic parts [Binasova 2014]. Its component parts are shown schematically in Figure 7.

Also, the implementation methodology should be treated as a unique project; therefore it is necessary to use methods of project management. These enabling assumptions are for every manufacturing enterprise different depending on the financial, tangible, intangible and human resources. By merging agents and holons into corresponding holon, layers of services can be created, which is compliant with SOA and at the same time with philosophy of the holonic systems.

For confirming the correctness of the methodology for reducing the energy intensity of production processes was selected manufacturing enterprises. These enterprises are engaged in manufacturing, selling tires and conveyor belts for the rubber industry. In selected manufacturing enterprises was verified the methodology for reducing energy intensity of production processes. For large content of data and breadth of verified methodology, we present the final conclusions and benefits:

- implementation of information campaigns to raise awareness about the opportunities and benefits of reducing energy consumption has led to optimization of production process in terms of energy use and increasing the overall equipment effectiveness,
- creating space for mutual communication and cooperation of production teams and energy management teams led to the development of optimization measures in the production processes, such as how to reduce emission,
- optimizing the use of information from the installed operating energy software has allowed generate monthly reports of energy consumption in the production process and has enabled the graphical visualization at visual management boards as tool for monitoring key performance indicators in production,
- application of standards for the promotion of energy efficiency of equipment and staff training for their correct implementation (setting state of hibernation mode of equipment, the implementation of autonomous maintenance, switch off lighting during breaks, etc.) allows reduction of energy consumption of individual facilities,
- introduction of information system has contributed to the exchange of experience about the possibilities of rational use of various energy devices,

– energy management team (based on established energy monitoring) has created the project to purchase additional diagnostic equipment and innovative technologies with high energy efficiency in the production processes.

5. CONCLUSIONS

The main scientific contribution is reference model CODESA that can be used to control and coordinate decentralized systems in heterogeneous applications and first concrete application into manufacturing domain CODESA-*Prime*.

This paper presents Manufacturing Multi-agent system with bio-inspired techniques: *CODESA-Prime* for control and coordination decentralized systems that are applied to manufacturing domain.

Prime uses indirect communication, based on pheromones, that eliminates drawbacks of multi-agent systems and can provide prediction horizon. Indirect communication is used for routing intelligent product through factory and resource allocation and routing logistics systems over a network of roads. Flow of pheromones can be adapted by testing ant-agent colonies ant genetics algorithms. *Prime* consists of three main agents, namely: Intelligent Order Agent, Intelligent Product Agent and Intelligent Resource Agent. Prime can be eco-friendly, supports cleantech, creating eco-innovation, monitor energy consumption, and propose corrective action.

Codesa-*Prime* has been tested in simulations for AGV systems, which have been tested basic aspects of multi-agent systems in Ella Software Platform. In further research, results should be transferred into industrial practice to control and coordinate AGV systems by company Central European Institute of technology (CEIT) located in Zilina, Slovakia.

Development of automation and intelligent manufacturing systems require energy-efficient design and its application. The proposed research is focused on analysis and optimization of tools for flexible energy use. Material flow integration should be developed, aiming at a holistic approach for resource management in process industries. Further research intends to specify the concept and to develop a demonstrator for using these methods by next case studies. The verified methodology for reducing the energy intensity of production processes can be implemented in other manufacturing enterprises.

The aim of the research is to determine visions, key research topics, barriers, impacts, key business scenarios and priorities, which can influence energy costs with low associated investment costs. New sources of productivity growth in the following stages of development will be certainly Artificial Intelligence (AI), application of knowledge-based systems and intelligent holonic solutions.

Advanced industrial engineering is focused on three main subgroups: industrial networks, adaptive production, digital engineering [Micieta 2014]. The ambition of future research work is to further develop a new practical concept of reconfigurable logistics system and on its prototype check the possibilities of its putting in the automotive and electronics industry.

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