Development of Working Scenarios and Strategies for Self-Organizing Production Systems

Marshall Plan Scholarship Report

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"Creativity is thinking up new things.

Innovation is doing new things."

- Theodore Levitt

1. Automotive industry in XXI

Automotive industry is very traditional, comparing to other industries. It develops very slow, and tries to increase productivity through the continuous improvement of production on place, but not through the big revolution steps. Nowadays an industry is at the edge of a big changes, which is caused by three factors.

The first factor is in a big gap between current IT possibilities and real implementation on the automotive plants. Nowadays, development of mechatronic systems, new control policies, augmented reality as well as whole boom of IT industry will lead to a big changes in a whole technology of the car manufacturing.

Second, a car itself will transform from just a mean of transport to a fully autonomous supportive system with huge amount of abilities. A traditional manufactures would have to adopt the production to more personalized, as well as shorter production cycles to be competitive on a market. For a customer of XXI century will be not enough just to have a typical mass-produced car, this car would be already “planned” with a customer, through choosing of a different features, options and other personalization.

At third, economically, a car industry is very dependent on the manual force of a plant operators. according to the US statistics department increase of the labor costs in manufacturing comes to more than 100% in most of the countries and up to 300% in several east-European countries. This is explained by globalization and high mobility level inside the EU.

To be competitive on today's market, a company should adopt to this fast changes and implement the new concepts of production, which would answer the requirements of these factors. (Becker, 2004)

There is one possible way for the manufacturer how to bring the production to a new level and adopt for the future changes. This could be done through a creation of new type of systems, which will be more effective to produce more on the same cost. This would give the same effect on a short run, but will give a company the advantages against the competitors in the future. It also would help to reduce the resources consumption, increase the utilization of machinery and makes the system more robust to a failure of one element.

2. System design

Design – it’s a process of constructing the action plan from the pure idea. It is the planning, which bases for the making of every object or system. It has different meanings in lot fields of studies. As a verb, "to design" refers to the process of originating and developing a plan for a product, structure, system, or component with intention.

For a design of manufacturing and production system is vital to know the exact definition of what a manufacturing or production system is:

Manufacturing systems defined by Suh as a subset of 3 different sets, see Fig. 1:

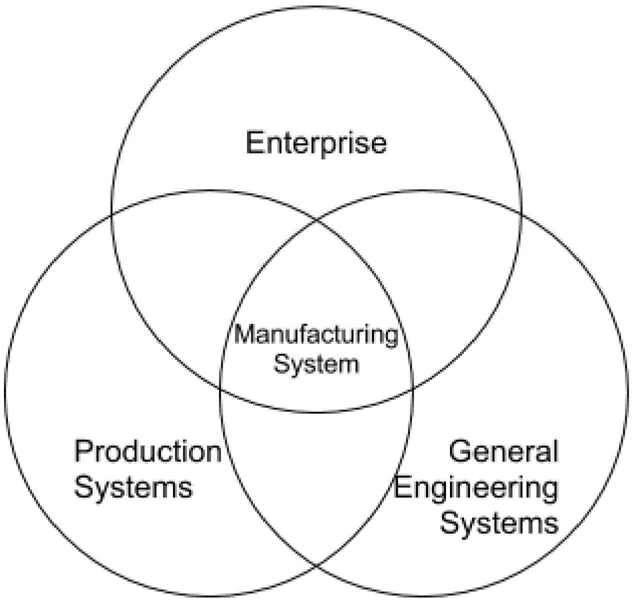


Fig. 1. Definition of manufacturing system through a subset (Suh, 1998)

- a production systems is defined as
- manufacturing enterprise
- general engineering systems

According to Groover *“Production systems are collections of diverse production resources like human resources, machines, equipment and procedures organized to accomplish manufacturing and/or assembly operations with the final objective to add value to a part or product”* (Groover, 2001).

Another definition is *“the arrangement and operation of elements (machines, tools, people and information) to produce a value-added physical, informational or service product whose success and cost is characterized by the measurable parameters of the system design”(Corchan & Lima, 1998)*

Assuming this definitions, production systems is a arrangement of working elements which is made to accomplish a manufacturing or assembly operations to produce value-added product.

Development of production systems in XX century changed an original systems dramatically. Implementation of computer control systems, ERP systems, as well as lean techniques changed a systems from just production of final product and pushing it to a market to a customized production for single customer order. Production systems of XXI century must answer following requirements:

- Long lasting performance
- Variability of products produced
- Defect free production
- Working modes reconfigurability
- 6Rs. **Right products** with The **Right quality** must be produced with a **Right quantity** in a **Right time**, sold with a **Right price** and delivered at **Right place**
- Ability to produce with a low quantities and high variability
- Minimized Work-in-Progress

*(Suh, 2001),(*Shanthikumar, 1986),(Matt,2006),(Katalinic, 2012a)

To fulfil the requirements the system design process should be planned accordingly.

2.1 System design procedure

There are following focuses in a system design exist in a literature
- flexibility(routing, volume, operation, product mix) (Suarez at al, 1991)
- agility (Yusuf et al., 1999)
- reconfigurability (Koren et al., 1999)
- changeability (Wiendahl & Heger, 2003)
- mutability (Spath & Scholz, 2007)

The most wide and detailed theory of system design - Theory of Axiomatic Design was developed by Professor Nam P. Suh with the original goal to develop a generalized, systematic, codified, and scientific procedure for design of products. Afterwards, it was adopted for a systems design.

Step 1. First of all there is a need to set a functional requirements (FRs) for a system. The main requirement of any business is a profit maximization or ROI(return of investment) maximization.

FR1 = Maximize the ROI (1)

The goal of a manufacturing system design decision is to make the system range inside the design range A productive manufacturing system must be designed to fulfil the main FR and answer the requirements stated above.

Step. 2. For the each functional requirement there must be a design parameter (DP) to satisfy this requirement exactly on this level. The FRs and DPs are described mathematically as a vector. The Design Matrix [DM] describes the relationship between FRs and DPs in a mathematical equation (Suh, 2001):

{FR} = [DM]{DP} (2)

With three FRs and three DPs, the above equation may be written in terms of its elements as:

FR1 = A11 DP1 + A12 DP2 + A13 DP3
FR2 = A21 DP1 + A22 DP2 + A23 DP3
FR3 = A31 DP1 + A32 DP2 + A33 DP3
(3)

Axiomatic Design is guided by two fundamental axioms that are basic for design evaluation and selection in order to produce a robust design (Suh, 2001):

"Axiom 1: The Independence Axiom. Maintain the independence of the functional requirements. The Independence Axiom states that when there are two or more FRs, the design solution must be such that each one of the FRs can be satisfied without affecting the other FRs". (see Fig.2)

"Axiom 2: The Information Axiom. Minimize the information content I of the design. The Information Axiom is defined in terms of the probability of successfully achieving FRs or DPs. It states that the design with the least amount of information is the best to achieve the functional requirements of the design."

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} * \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$$

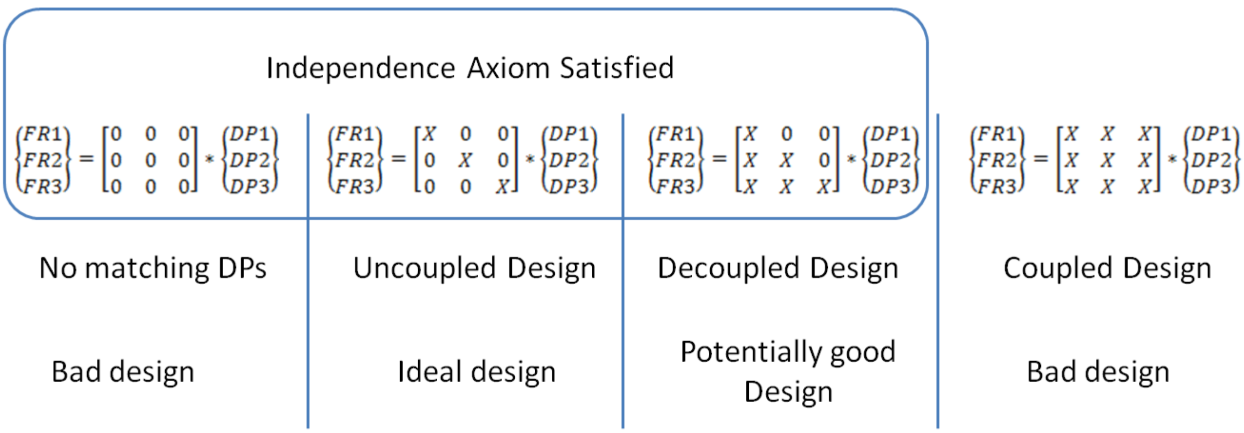


Fig.2. Comparison of different FR-DP relations

For our FR1 there are 2 possible DPs could be proposed:
DP1a = Manufacturing system to provide a lot of products at minimal costs and push them to a market

DP1b = Manufacturing system to provide high quality products that meet customer needs

Choosing between this options plays huge difference in a whole system design. After the set of DPs all the options must be analyzed and the best design for this level must be chosen. At this step DPs should be compared with production requirements. DP1a will not satisfy a *Variability of products produced* requirement, so DP2 will be chosen.

Step 3. FR should be decomposed for the reaching real design steps and initiatives. FR1 could be decomposed, which is equivalent setting the functional requirements to satisfy the DP chosen. This decomposition will strongly depend of chosen DP. In our case,

DP1b = Manufacturing system to provide high quality products that meet customer needs will be decomposed for a following FRs. A definition of ROI is in (4)

$$ROI = (Sales - Costs)/Investment \quad (4)$$

A classical approach used in 1913 was developed by Henry Ford, when mass-production was realized using following FRs

FR11a = Increase the sales revenue
FR12a = Minimize the manufacturing cost
FR13a = Minimize manufacturing investment

According to the current requirements following DPs could be alternatively set. For that (4) should be transformed in a following way:

$$ROI = Profit/Investments \quad (5)$$

Profit could be defined as 5

$$Profit = (Ppu - Cpu)*Q*T \quad (6)$$

where Ppu - Price per unit
Cpu - Costs per unit
Q - Number of pieces produced daily
T - Number of days in operation
So, from 4 and 5

$$ROI = (Ppu - Cpu)*Q*T/Investments \quad (6)$$

According to 6 following requirements could be set

FR11b: Sell at the maximum possible price
FR12b: Produce at a minimum costs per unit
FR13b: Sell stable quantities
FR14b: Maximize the time of the system utilization
FR15b: Minimum of additional investments

For that FRs following DPs could be considered:
DP11b: Produce to demand
DP12b: Minimize cost per unit
DP13b: Produce multiple products
DP14b: Design of easy reconfigurable system
DP15b: Maximal autonomy of a system elements

$$\begin{Bmatrix} FR11b \\ FR12b \\ FR13b \\ FR14b \\ FR15b \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} * \begin{Bmatrix} DP11b \\ DP12b \\ DP13b \\ DP14b \\ DP15b \end{Bmatrix} \quad (7)$$

A design solution on a first level is uncoupled. Any of DPs would be decomposed at the second level. From this point, the mark b will be no more relevant because option is already chosen. Matrix could be presented as (8)

$$\begin{Bmatrix} FR11 \\ FR12 \\ FR13 \\ FR14 \\ FR15 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} * \begin{Bmatrix} DP11 \\ DP12 \\ DP13 \\ DP14 \\ DP15 \end{Bmatrix} \quad (8)$$

For the DP11 a decomposition would be following (Matt, 2008)

<u>DP11: Produce to demand</u>
- FR 111 Identification the required output rate
- FR 112 Continuous flow creation
- FR 113 Quick response to unplanned production problems
- FR 114 Production disturbances maximization by planned standstills
- FR 115 Operational flexibility achievement

<u>DP12: Minimize cost per unit</u>
- FR 121 Minimize labor costs
- FR 122 Achieve a high yield of acceptable work units
- FR 123 Minimize one time expenditures

DP13: Produce multiple products
- FR 131 Machinery for each operations
- FR 132 Operators skilled to produce more products
- FR 133 Products scheduling system

DP14: Design of easy reconfigurable system
- FR 141 Single production stations
- FR 142 Easy layout reconfiguration

DP15: Maximal autonomy of a system elements
- FR 151 Easy exchangeable elements
- FR 152 Each operation is backed up
- FR 153 Independent internal logistics system

For each of this FRs optimal DPs should be provided. With a zigzagging between FRs and DPs, as it was shown on the first level, the DPs of the second level should answer the corresponding FR.
Most of the production companies strive to make DPs similar to Matt (Matt, 2006)
DP-11 Determine and produce to takt time (for details see: Matt, 2006 and Matt, 2008)

DP-12 Define a case of production

It is a very important step in a system design. There are two different criteria - quantity and variations. Some factories produce a lot of different products but in low or medium quantities. Another plants have a specialization in high production of only one product type. Different products have different shapes and sizes and styles, they perform different functions, they are sometimes intended for different markets, and some have more components than others. There are 3 different cases could be set:

1 Single model case
2 Batch model case
3 Mixed model case

The first two cases are well known and design of them is widely described in a literature. The third case is normally solved with an optimization of process layout (Fig. 3).

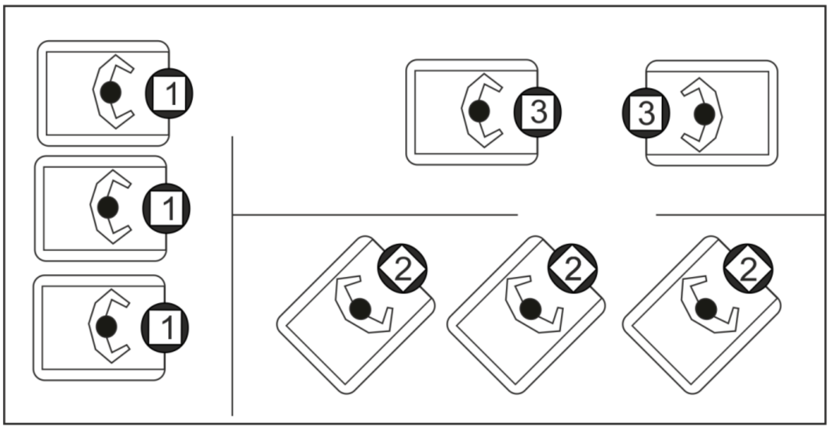


Fig. 3. Process plant layout

The process layout is noted for its flexibility; it can accommodate a great variety of alternative operation sequences for different part configurations. Its disadvantage is that the machinery and methods to produce a part are not designed for high efficiency. The case of mixed model could be divided into 2 subcases, depending of a lead time:

- Non-variable lead time. Lead times of a single process are constant or vary not wide. This variation could be neglected by line balancing. In this case sequential multi-station system with fixed routing is proposed.

- Variable lead time. Lead times of the single process steps vary widely and cannot be balanced . This case is not well described in a literature, and traditionally requires complex means to solve the times disbalance. A Bionic Assembly System concept is designed for this case. Working modes simulation could be found in chapter 4.

Other design parameters are standardized and discussed in (Matt.2006)

DP-113 Visual control and fast intervention strategy (Introduction of TPM – Total

Productivity Maintenance)

DP-114 Reduction and workload optimized scheduling of planned standstills (TPM)

DP-115 Setup reduction (Optimization with SMED – Single Minute Exchange of Die)

The effective design parameters (DPs) for FR-121 - FR-123 are the following

DP-121 Quality control implementation
DP-122 Effective use of recourses
DP-123 Investment in modular system components based on a system thinking approach (Matt, 2006)

The effective design parameters for DP131-133 are following:
- DP 131 Combination of single and multi-operational machinery
- DP 132 Trainings for an operators
- DP 133 Organization of scheduling system

The effective design parameters for DP141-143 are following:
- DP 141 Design of standardized production stations

- DP 142 Design of movable stations

The effective design parameters for DP151-153 are following:
- DP 151 Standardized elements
- DP 152 Communication field for the elements
- DP 153 Line-less system concept

A design parameters are decoupled, that would answer the Independence Axiom. A full tree of design parameters is shown in a Fig. 4.

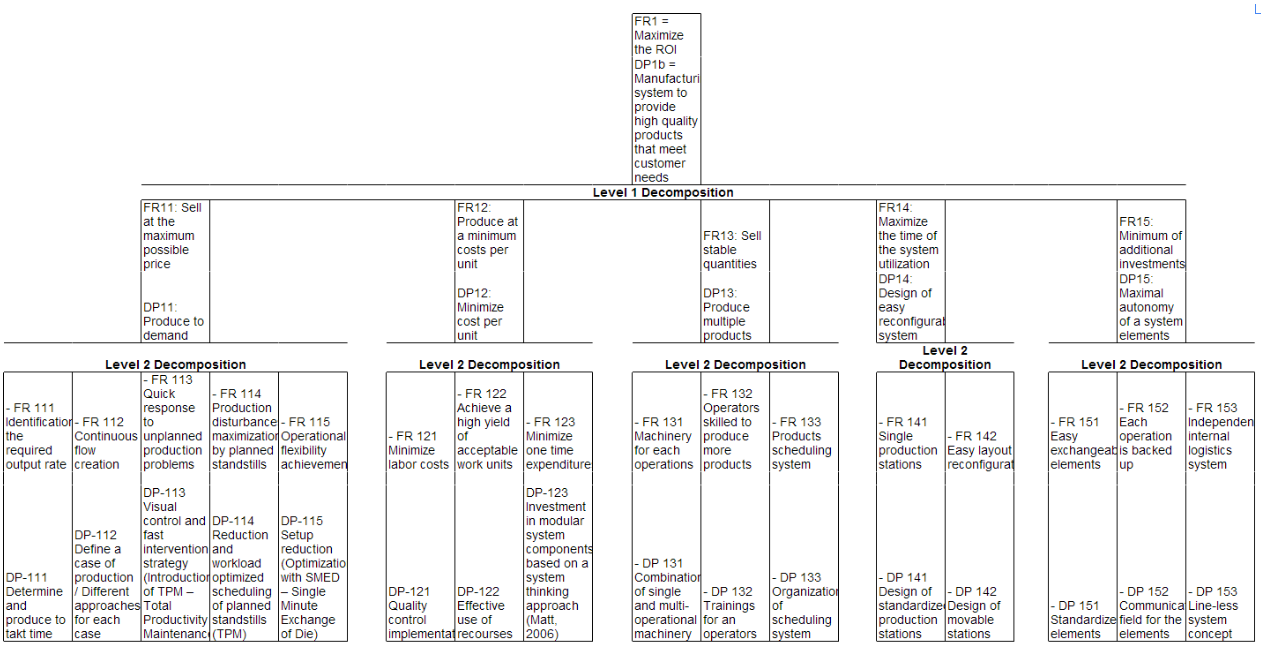


Fig.4. Tree of Design Parameters

3 The way of process improvements

There are thousands of different improvement techniques or an industrial processes. Improvement is actually also a process, which could be standardized and described. Expression *lean + …* , which is one of the most used in industry is also one of the techniques of processes improvement.
First of all, to improve the processes, there should be an understanding what a process itself is.

Merriam-Webster's Definition of PROCESS (ref)
a *(1)* ***:*** *a natural phenomenon marked by gradual changes that lead toward a particular result <the process of growth>*

b : *a series of actions or operations conducting to an end;*
especially ***:*** *a continuous operation or treatment especially in manufacture*

Process could be defined as a *series of actions* or a *continuous operation,* which are made to achieve a planned goal.
Some processes are formal and huge in scale. Some of them are strict, documented, and widely used across an organization. They could consist of sub-processes , like shown in Fig. 5.

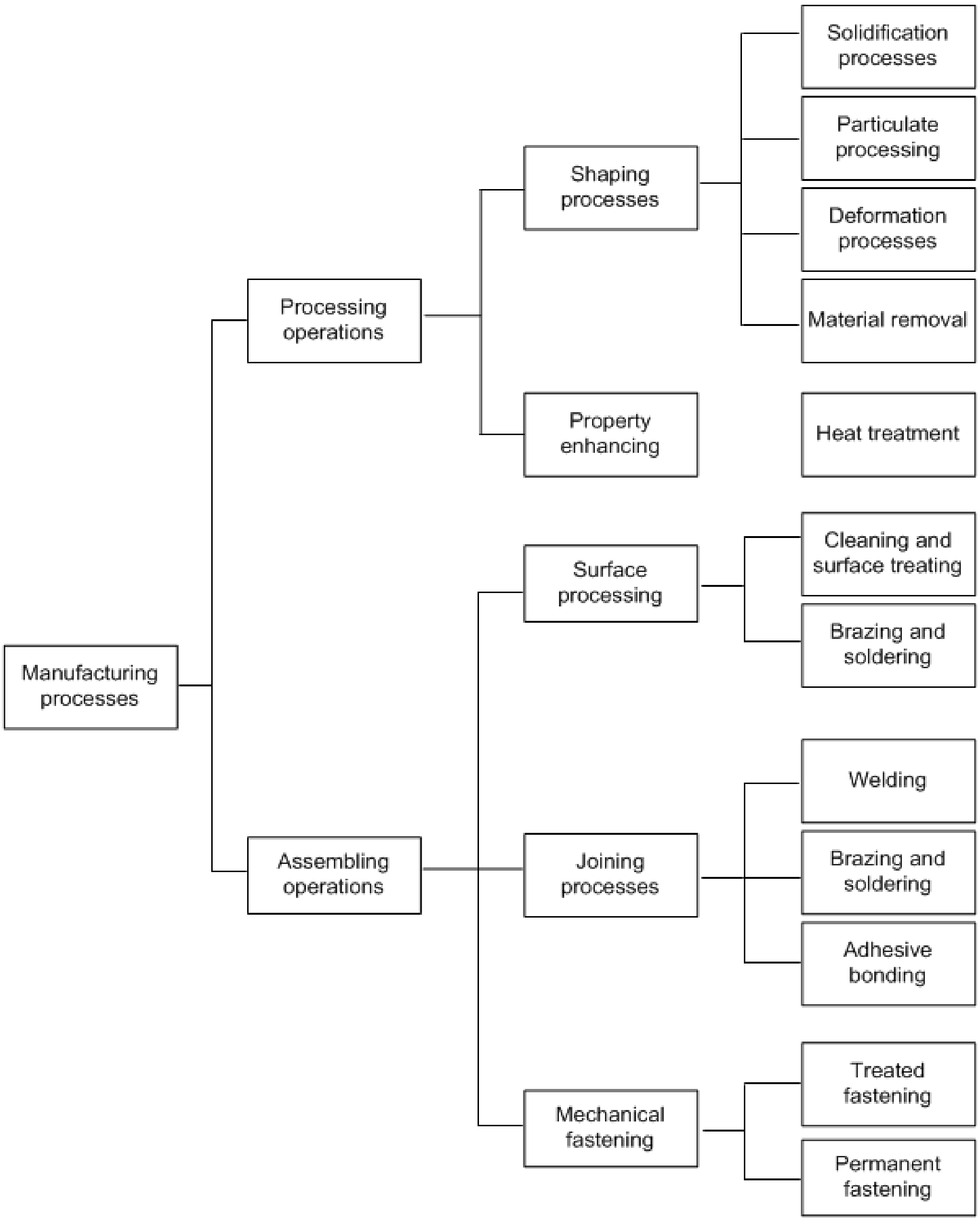


Fig.5 A tree of manufacturing operations (Groover, 1996)

Another ones are smaller, could be undocumented, some of them could be hidden. But to make a big scale production function, all the processes must taken into a consideration and conducted at a right time.

1.Work Order release

It is a starting process for an any of production processes. It defines what, how, and in which quantity may be produced. An order could be a single or could consist of a sequence of an orders. For an production planning is very important to plan a work orders realization. orders are realized in a first-in-first-out sequence. In some systems for a higher flexibility orders could be prioritized. Prioritizing gives an ability to speed up a production process for some important orders, and slow down less important ones. a sequence of orders could be automated with a use of ERP systems, like SAP.

2. Production Planning

When sequence of orders is realized, technically everything should be ready for a production. In our case we assume that all machines are in place. There are following criterias for a checking before a production start

- Elaborating of conception of emergency plan
- Analysis of risks as to process
- Determining of alternative machines as for production of parts
- Determining of minimum stock as to in-house parts
- Analysis of logistics
- Check of emergency operation of automatic transport and storage systems
- Emergency planning of transport logistics (alternative routes, accessibility, accident, etc.)
- Check of use of alternative packing
- Check of implementing of back-up system
- Analysis of risks for purchasing
- Determining of emergency store at raw material suppliers
- Determining of safety stock at suppliers of purchased parts
- Proposal of emergency plan

2.1 Production release

After all system is analyzed, all the risk factors are identified and emergency scenarios are written, production is ready to be started. By this time all the production elements: tools, materials, operators must be on a shop floor. Production stops and starts again after each cycle (shift, day, end of working order)

3. Plant Production Process Chain

For each of the products there is own process chain which includes necessary processes. For a case of bumper production following processes are included:

3.0 Extruding of Composition Materials
3.1 Injection Molding
3.2.Painting Ext. LBC
3.3 Painting Int. LBC
3.4 Forming
3.5 Laminating (Vacuum or Press)
3.6 Foaming

3.7 Slush
3.8 Painting Ext NBK
3.9 Assembly (with welding)
3.10 Order Picking (JIS)

Some of this processes consist of another, smaller processes, which are shown in Tab.1.

Table 1.Example of a processes and sub-processes for a bumpers production

Process	Sub-process
1.Work Order release	
2. Production Planning	
2.1 Production release	
3. Plant Production Process Chain	
3.0 Extruding of Composition Materials	
3.1 Injection Molding	1.Work Order release 2. Production Planing; 2.1 Production release 3.1 Injection Molding: 3.1.1 Transport of material (silos, octabins) 3.1.2 Drying, 3.1.3 Transport to injection molding machines, 3.1.4 Closing the mold, Injection, Pressure, Cooling and plastification, Opening the mold 3.1.5 Ejecting the part and transport to working place 3.1.6 Processing and checking the part 3.1.7 Pre-assembly, 3.1.8 Packing, 3.1.9 Delivery
3.2. Painting Ext. LBC 3.3 Painting Int. LBC	1.Work Order release 2. Production Planing & Production release 3.2.1 Preparing of paint material, 3.2.2 Preparing parts for painting, 3.2.3 Masking, 3.2.4 Putting onto skids, 3.2.5 Checking skids, 3.2.6 Coding, 3.2.7 Washing, blowing, 3.2.8 Drying and cooling 3.2.9 Flaming, 3.2.10 Base and Clear Coating, 3.2.11 Evaporating, drying, cooling,

	3.2.12 Hanging parts off 3.2.13 Checking 3.2.14 Assembly, 3.2.15 Packing
3.4 Forming	
3.5 Laminating (Vacuum or Press)	
3.6 Foaming	
3.7 Slush	
3.8 Painting Ext NBK	
3.9 Assembly (with welding)	1.Work Order release 2. Production Planing 3.Plant Production Process Chain 3.7 Assembly (with welding) 3.7.1 Ordering of parts, 3.7.2 Receiving parts 3.7.3 Preparing parts for assembly, 3.7.4 Assembly 3.7.5 Special assembly operations (welding, milling,...) 3.7.6 Checking final parts 4. Delivery
3.10 Order Picking (JIS)	

Table 1. Example of a processes for a bumpers production

As it seen from a Table 1,there are lots of processes in production and there are a lot of them, which directly or indirectly influence on each other and general system performance. With a development of technologies, introduction of a new products and processes, a system should be constantly reconfigured and improve in order to achieve a production excellence.

3.1 Process improvement techniques

Process improvement could be made iin all kind of anl organizations, and there many different approaches for that. These approaches could have different goals and focuses, could concentrate on different aspects of the process. There are also lots of different definitions of process improvement in a literature, and this section contains the definitions which are relevant for this thesis.

According to Webster, improve means “to bring into a more desirable or excellent condition” or “increase in quality or value” [Webster]. So, process improvement leads to an increase in the value or quality of the process. Improvement of a production processes could be done in a 3 different areas.

There are two most common targets for improvements of the processes.

The first one concentrates on a product itself. An aim of this improvements to increase the quality of a product by improving customer satisfaction, defect rate, performance. This approach is standardised and described in ISO-9000 and Business Process Reengineering (BPR) standards.

The other focus for improvement is the process itself. This approach stays on a process quality definition, and aims to improve aspects like efficiency, predictability, scheduling and conformance. The product of the process might have some importance in this approach, but only as an indicator for process quality.

1) Time reduction. When process time is shorter, than system could produce more in a same period of time, which leads to higher profit.

2) Waste reduction. When waste number is less, than system could also produce more in a same period of time, which leads to higher profit

3) Costs reduction. The costs of a process could be reduced with use of an optimization instruments, which would lead to a higher profit.

Waste reduction could be considered as a quality increase, as costs and time reduction to a value increase. But all of the processes improvement initiatives have only one final goal - a profit increase (Fig.6)

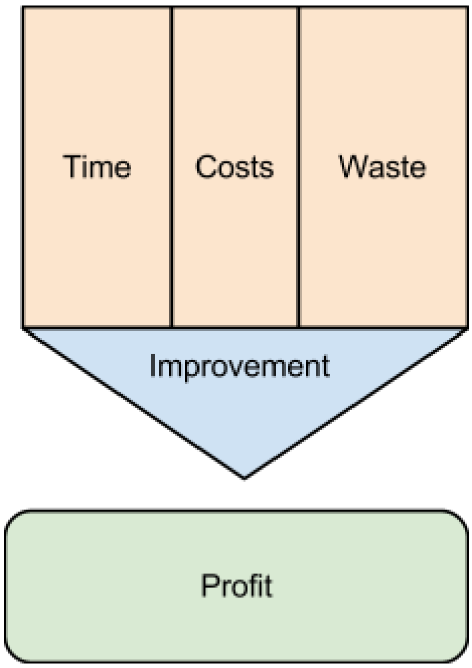


Fig. 6. Main reason for improvement of processes

There are 2 different ways in a technology and process improvement. The first one is continuous improvement, also known as *kaizen* originated from Toyota Production System. Another one is innovation - the introduction of something new to existing processes. A comparison of this two methods is shown in a Table 2.

Table 2. Comparison of a process improvements techniques

Criteria	KAIZEN	INNOVATION
Effect time and volume	Long term and long lasting but undramatic	Short term but dramatic
Rate of changes	Small steps	Big Steps
Spark	Conventional know-how and state of the art	New inventions, technologies, breakthroughs
Effort orientation	People	Technology
Evaluation criteria	Results for a process excellence	Results for profit

Kaizen is defined as a continuous improvement. A word itself Kai Zen (改善) could be translated as change for the better, means just an improvement. This improvement goes in a very small steps and with a shorter scale of changes, but very often. Effect of innovation is huge, but there is a need in a time to develop and implement a new process or system. Innovation way of improvement is technology-based and orients to get a higher profit right after an implementation. Kaizen is driven by people doing this process, to daily improve the productivity of a workers.

Fig. 7 shows a difference between kaizen and innovation in a time-improvement space. Kaizen improvements are *smaller* and *faster,* and innovation approach is longer in preparation but change of improvement is much bigger.

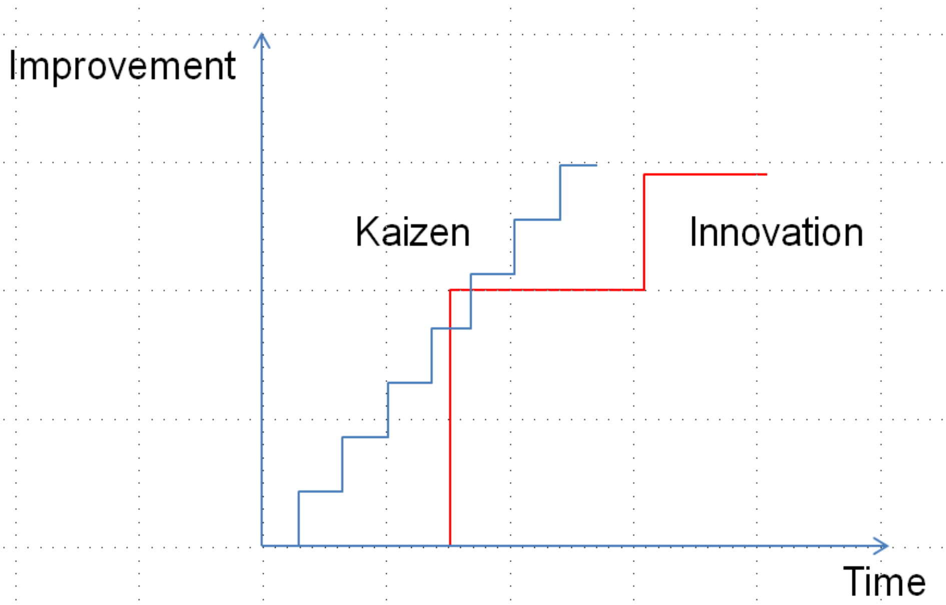


Fig. 7. Comparison of kaizen and innovation

In some factories kaizen activities are crashing against the need to constantly rebalance the lines because the average volume per day and the takt time kept changing during this period (Pardi, 2006b).

A balancing problem could be solved by the development of reconfigurable multi-product system with an exchangeable, movable components. This system should adopt to a changes of an environment and self-organize.

4 Self-organization in nature and technology

Self-organization – it's a term, which cannot be explicitly defined. Connected to engineering, the definition of self-organization is the ability for the number of working elements to be a system without any leading element or external control. Examples from biology, physics, and economics can prove that such a system can exist.

The term was introduced in science in 1947 by W. Ross Ashby. Specifically, self-organization refers to systems in which the internal dynamics tend to increase order.

4.1 Definitions of self-organization

To get the definition of self-organization, the definition of organization must be considered.

First of all, organization is an act or process of putting the different parts of something in a certain order so that they can be found or used easily. Second – the way in which the different parts of something (such as a company) are arranged (Merriam-Webster dictionary).

The synonyms of the organization are assembling, construction, coordination, design, formation, grouping, harmony, management, methodology, organism, pattern, plan, planning, regulation, standard, standardization, structure, structuring, symmetry, system, unity, whole (thesaurus.com).

Using this definition with prefix self-, we'll get general definition of self-organization: the way in which the parts are arranged into a system, without any external control. There are a lot of definitions in the different spheres of science; main of them will be shown below.

Ability of a system to spontaneously arrange its components or elements in a purposeful (non-random) manner, under appropriate conditions but without the help of an external agency. It is as if the system knows how to 'do its own thing.' Many natural systems such as cells, chemical compounds, galaxies, organisms and planets show this property. Animal and human communities too display self-organization: in every group a member emerges as the leader (who establishes order and rules) and everybody else follows him or her, usually willingly" (businessdictionary.com)

Another description is given by S. Camazin: *"Self-organization is a process whereby pattern at the global level of a system emerges solely from interactions among the lower-level components of the system. The rules specifying the interactions among the system's components are executed using only local information, without reference to the global pattern.*" (S. Camazin, J.-L. Deneubourg, 2001).

In other words, self- organization is the ability of the system to make an order out of chaos without any external exposure.

5 Concept and working elements of Bionic Assembly System

In a first part there were discussed the requirements for a new generation of production systems. This requirements are set for a goal of long-lasting system performance and easy reconfigurability.

From (Suh, 2001),(Shanthikumar, 1986),(Matt,2006),(Katalinic, 2012a), (Setchi, 2004) there are following requirements for a new generation of production systems set.

Absence of a destruction poin
Defect free production
Long lasting performance
Minimized Work-in-Progress
System components simplicity
System Modularity
Variability of products produced
Working modes reconfigurability

In a chapter 2 the following design parameters are developed to fulfil this criterias (Tab. 3). This parameters must be taken into a consideration for a new system design

Table 3. Design parameters for a Bionic Assembly System

DP-111	Determine and produce to takt time
DP-112	Define a case of production / Different approaches for each case
DP-113	Visual control and fast intervention strategy (Introduction of TPM – Total Productivity Maintenance)
DP-114	Reduction and workload optimized scheduling of planned standstills (TPM)
DP-115	Setup reduction (Optimization with SMED – Single Minute Exchange of Die)

DP-121	Quality control implementation
DP-122	Effective use of recourses
DP-123	Investment in modular system components based on a system thinking approach (Matt, 2006)
DP-131	Combination of single and multi-operational machinery
DP-132	Trainings for an operators
DP-133	Organization of scheduling system
DP-141	Design of standardized production stations
DP-142	Design of movable stations
DP-151	Standardized elements
DP-152	Communication field for the elements
DP-153	Line-less system concept

An initial concept of a system is developed and described by Katalinic (Katalinic, 2001). A concept layout is shown in a Fig. 8. A main element, which creates self-organization is a swarm of mobile robots. This are autonomous machines, which deliver a assembly pallets through assembly stations instead of a conveyors or manual operators.

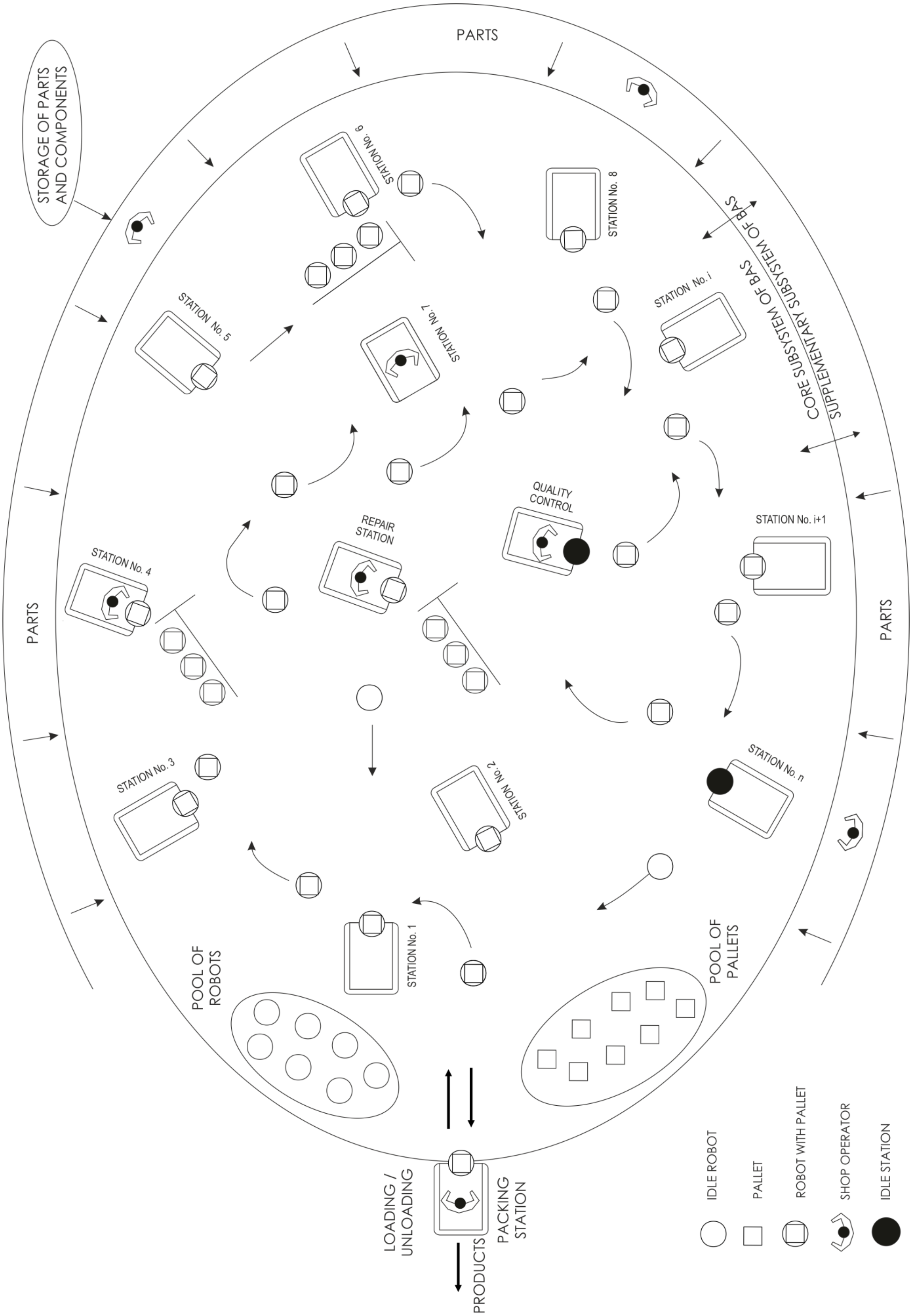


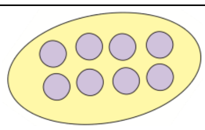
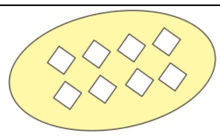
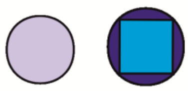
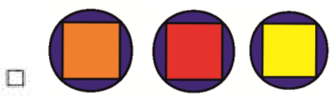
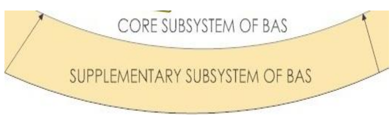
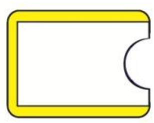
Fig. 8. Initial Layout of a Bionic Assembly System (Katalinic & Kordic, 2002)

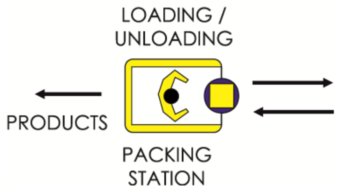
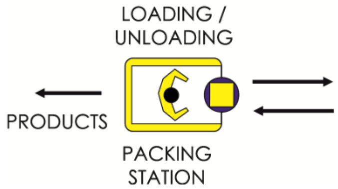
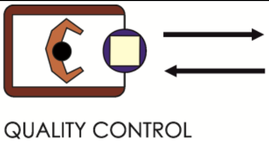
All the events are happening on a shop floor, inside of a factory. Assembly area is separated, and assembly stations configuration looks as it was shown in Fig. 7. BAS is divided on a two subsystems. Supplementary subsystem is responsible for a parts supply and system servicing.

Internal or core subsystem includes a playground includes 14 stations, pools of pallets and robots. Mobile robots are moving freely in this environment and would have to avoid obstacles and another robots while moving.

Robots are following the scenario of shortest time order completion. Order is a sequence of operations, which could be done on one or more stations. Robot needs to choose the best possibility. The best means minimal time for an order completion. It can happen, that more than one robot want to make the same operation at the same time. Then rule first-in-first-out is applicable. Then another one should wait in a queue for his operation. Time includes transport time, time in a queue and a time of assembly operation. To control an ability of the system to produce JIT, system of priorities is introduced. Robot with a higher priority would go first in a queue, and robot with a lower one, should allow it to go. Table 4 shows the brief description and functions of a BAS system elements.

Table 4. Description of self-organizing system elements

Element	Sign on the scheme	Main functions
Pool of robots		Storage, charging and servicing of mobile robots
Pool of pallets		Storage of an empty assembly pallets
Mobile robot		Carrying assembly pallets through the system to fulfill assembly operation in a shortest time
Assembly pallet on a mobile robot		Connects vertical and horizontal systems in BAS. A unit which contains information about an assembly order status and priority
Storage of parts and components		Storage parts, tools and components for a system needs
Assembly station		Generalized machine unit for assembling operations

Loading/ unloading station		Taking out existing pallets from the system
Packing station		Remove of products and packing for transportation
Quality control station		Station which makes quality control, through measurement of product parameters
Repair station		Making repair of the incorrect orders

More about priorities and reconfiguration could be read in (Katalinic, 2012). More information structure, functions and characteristics of this system is described at (Katalinic,2001), (Kordic, 2002).

5.1 Mobile robot in BAS concept

A field of control of mobile robots is very wide and multidisciplinary. In this paper we would like to speak about an industrial application of mobile robots in assembly area. Comparing to other production processes, this area has a lowest level of automation. Optimization of assembly goes slowly. Traditional systems use assembly lines (reference), and balance them for a mix of the products(ref). This helps to increase the effectiveness, but a speed of an assembly line would be always equal for a speed of the most complex model.

Another solution which allows great scalability and makes possible to assemble multiple products in one system is usage of a mobile robots on a shop floor. This increases a flexibility and gives the possibility to avoid special line balancing and reconfigurations.

Industrial use of mobile robots is very limited. Most of the systems are designed for AGV (Automated Guided Vehicle) usage. The AGV approach is described by Le-Anh and De Koster. It helps the companies to automate the delivery on the plant and reduce a work of forklifts operators. This approach works well in a warehouses of plant logistic systems, where no flexibility is required. AGVs have low intelligence, all the planning and coordination is processed by central computer. Also, AGV normally follows one magnetic line, which follows to a blockage in case of the AGV failure.

Another option, to use a swarm of mobile robots. An application of this distributed system could be found in (Guizzo,2008) and here (fraunhofer). It's applied in an warehousing logistics, and has better performance than AGV because of the following features:

- Flexibility. The system could be reconfigured and mobile robots have an ability to travel through a shop floor.

- Scalability. The capacity of the system is not limited by the number of system elements. Moreover it could be reconfigured to work in a most efficient way.

- Higher intelligence. Mobile robots have intelligence inside, and could sense the position of others and avoid collisions. In a case of robot failure, it will not disturb others because of the sensing possibilities.

Using this features, the systems are very suitable for a warehouse logistics. A layout of the warehouse allows to divide the space for a squares and navigate mobile robots through the whole space using QR-codes on the floor.

Fig. 9 shows the comparison chart between a different types of mobile robots. AGVs are normally following a magnetic line and operated by central control system, what gives low flexibility and level of intelligence. Centralized mobile robots (CMR) are used in warehouse logistics. They are equipped with a different range of sensors for navigation, what gives robot an ability to travel within the grid, with 90 degrees turns. This approach has better flexibility than AGVs. The obstacle avoidance, as well as robot path planning is operated by central system, so intelligence could vary from low to a medium level, depending on the centralization.

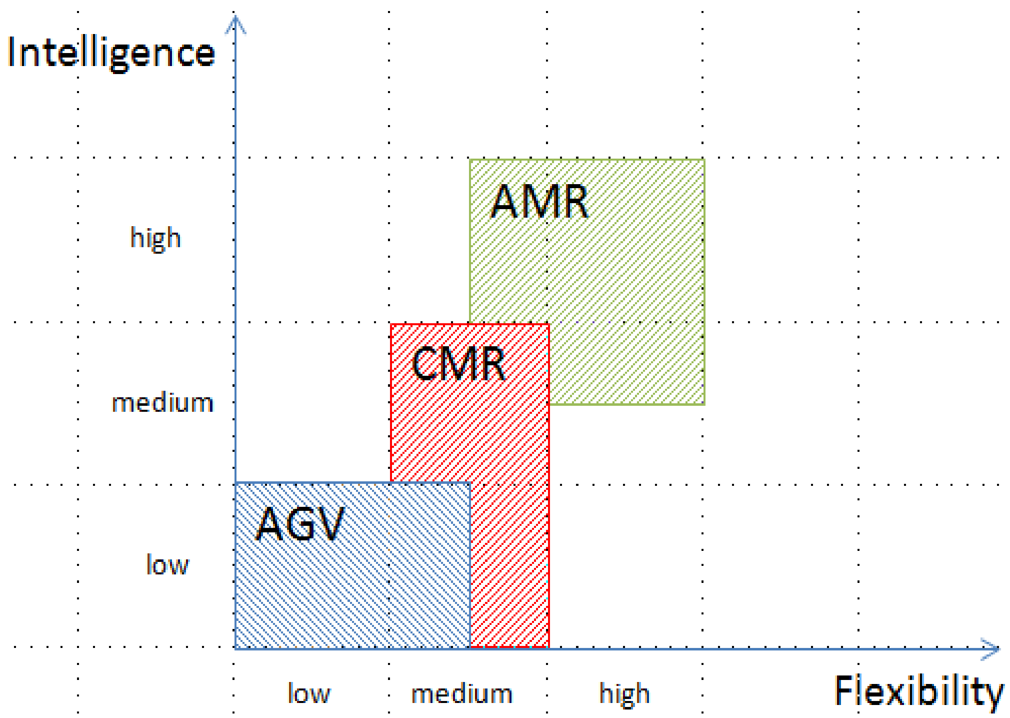


Fig. 9. Comparison of different types of mobile robots on intelligence-flexibility space

Third type of the robots are the AMRs - Autonomous Mobile Robots. This robots could have the highest level of intelligence and flexibility, because of ability to plan, act and reconfigure autonomously. The main task of the control system is to assist the robot with needed information and organize the work of assembly stations. AMR plans a track, avoids collisions using local sensors and makes a needed sequence of operations. From all of the mobile robots, this type is the most similar to a forklift operator.

For an assembly area is not always possible to organize the square space, as well as centralized control of the whole mobile robots. Assembly automation requires high flexibility, as well as high intelligence of mobile robots. This is determined by different sequences of operations and requirement to have no single breaking point in a system. That's why it is preferable to use AMRs as a key part of new type of an assembly systems.

Research in this field could be found in works of Ueda. Continuous research in an application of multi-robot systems in assembly area is carried out by IMS group of Vienna University of Technology. The concept of an assembly system is called Bionic Assembly System (BAS). The results may be found in (Katalinic, 2012), (Kukushkin, 2012)

Idea of this paper to develop an algorithm for a swarm of mobile robots to fulfill a sequence of operations to assemble one piece of product. Most of this systems are centralized. The tasks are fulfilled by mobile robots, which are controlled from one central computer. Mobile robots just following the paths which are given by central computer, and have no information about others, and about an order, which they fulfill. This approach is well known in a literature and used in industry.

But an applicability to an assembly area requires an absence of one destruction point and ability of the system to function even if some elements are down. This requirement comes from JIT and JIS pull concepts of planning, where products are produced, assembled and delivered on a request of a customer and exactly to a requested day and in requested sequence.

This strategy doesn’t allow a manufacturer to keep a big stock. That’s why it is essentially important for a manufacturer to have a system, which has no destruction point and would keep working in one or more components failure. This would keep a delivery time constant. So, the best possibility will be to use a decentralized system, where agents will be doing own task and a task planning and fulfillment would be not controlled by a central computer.

This approach gives an agents of a system “higher” intelligence, what means that this agents would be responsible for its own task fulfillment, as well as planning of its own activities.

Mobile robots in BAS must follow working algorithm and able to act and fulfill it autonomously. The algorithm is shown in a Fig. 10

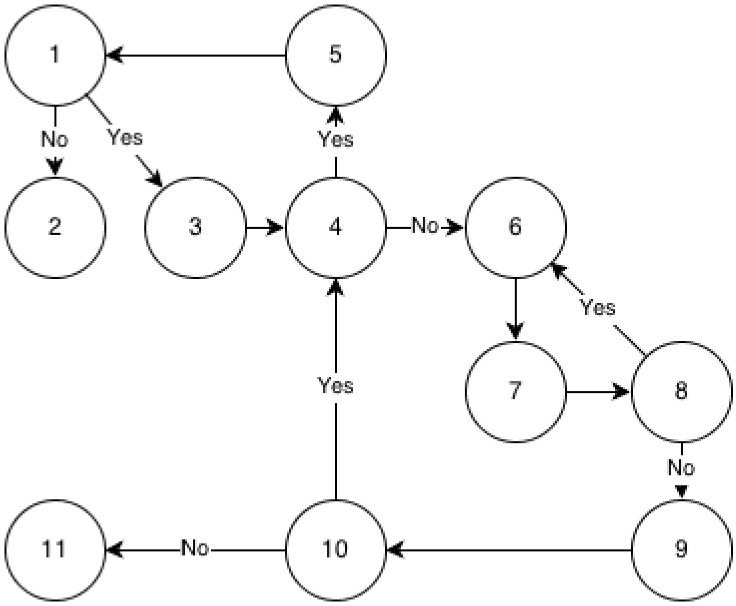


Fig. 10. BAS Mobile robot working algorithm

Step 1. All the robots are in a sleeping mode in a pool of robots. After the switching on, robot must check if the battery is fine and there are orders to fulfill.

Step 2. If there is some problems with a battery or there is no order to fulfill, robot goes to pool of robots

Step 3. If battery level is high and there are orders, robot goes to a pool of pallets and takes a pallet

Step 4. Each of the pallets has its own tag. Through this tag mobile robot is able to decode an information about a pallet status. This information is called assembly matrix. From an assembly matrix is possible to read if a last operation on a pallet and get the next one. Robot needs to read an assembly matrix.

Step 5. If there is no more assembly operations on this product, robot has to go to a packing station. On the packing station, product is taken from a pallet, packed and sent for a delivery. A pallet is reset and returned to mobile robot.

Step 6. If there is a assembly operation in a list, mobile robot has to fulfill it in a shortest period of time. Time is calculated using formula 9. Tas- is a time of assembly operation, Tq - is time of waiting in the queue in front of one station, and Ttr is a transportation time, or the moving time between the stations.

$$T=Tas+Tq+Ttr \quad (9)$$

Tq could be calculated as shown in 10. Tq is a sum of the Tas of the whole robots of higher or the same priority in front of the mobile robot.

$$Tq = \sum_{k=0}^{n} Tas_k \quad (10)$$

For BAS is normal to have multiple stations for the each assembly operation. It helps to keep a flexibility and absence of a single breaking point of a system. Robot checks which stations are available and calculates T for each of a stations. After a calculations robot chooses a minimal T and drives to a needed station.

Find and choose the best assembly station procedure consists of 5 steps

{

1) See which stations are able to make this step.

2) See what are the times of an operation

3) Look on a queue before each station

4) Sum assembly time for each robot of a higher or equal priority in a queue

5) Estimate Travel time

6) Sum all the times

7) Choose a minimal time

}

Step 7. After an assembly station is chosen, robot drives to this assembly station

Step 8. If there are robots of higher or equal priority in front, it waits in a queue. Robot could leave a queue only through assembly operation or through a change of a conditions. If there is a new station opens, a current assembly station fails or robot with higher priority comes in front and changes a Tq of a station, it has a right to reconfigure. A reconfiguration procedure is described in (Kukushkin, 2011)

Step 9.If there is no more robots in front queue, robot drives inside a station. Assembly pallet is taken and docked at the station, and returned back with an updated tag after an assembly operation. If a quality of an operation or product is not OK, quality status of a pallet is changed and pallet is returned to a robot

Step 10. Robot checks if a quality status of a pallet. In a positive case it returns to Step 5.

Step 11. If a quality status of a pallet is negative, robot goes to a repair station, where repair operation would be done.

This algorithm is realized in frames of Anylogic modeling software. Algorithm realization is shown in a Fig. 11.

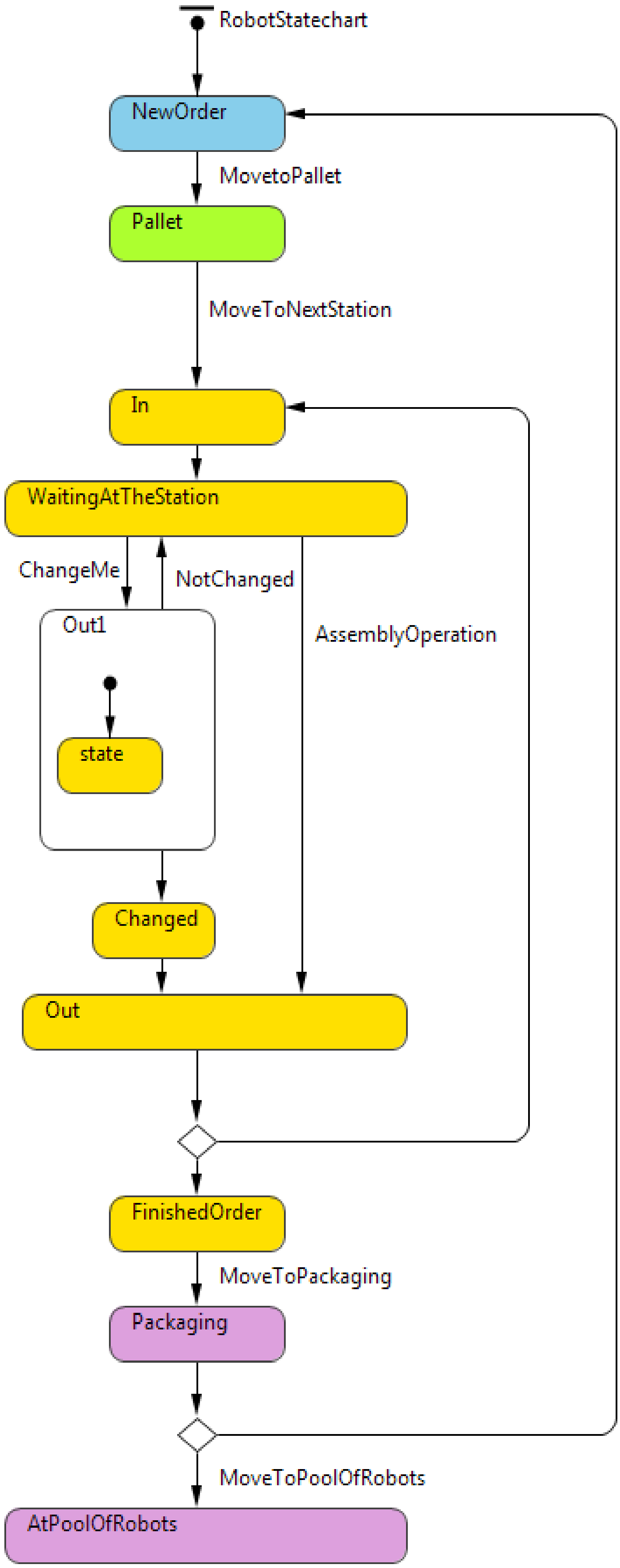


Fig. 11. BAS Mobile robot statechart realization in Anylogic

5.3 Communication in BAS

There are 2 different types of communication existing within the system– 2 models, vertical and horizontal. From the vertical level, this system is connected to an ERP system of the whole factory, through in the systems gets the orders to fulfill Just-in-Time.

System design allows communication between system elements. To avoid a lot of transmission between an agents, a transmitting framework is proposed. Elements would communicate through a cloud, which can be secured and constantly updated. Each robot and station would upload info to a cloud and it would be transmitted to everyone. Communication scheme is shown at Fig. 12.

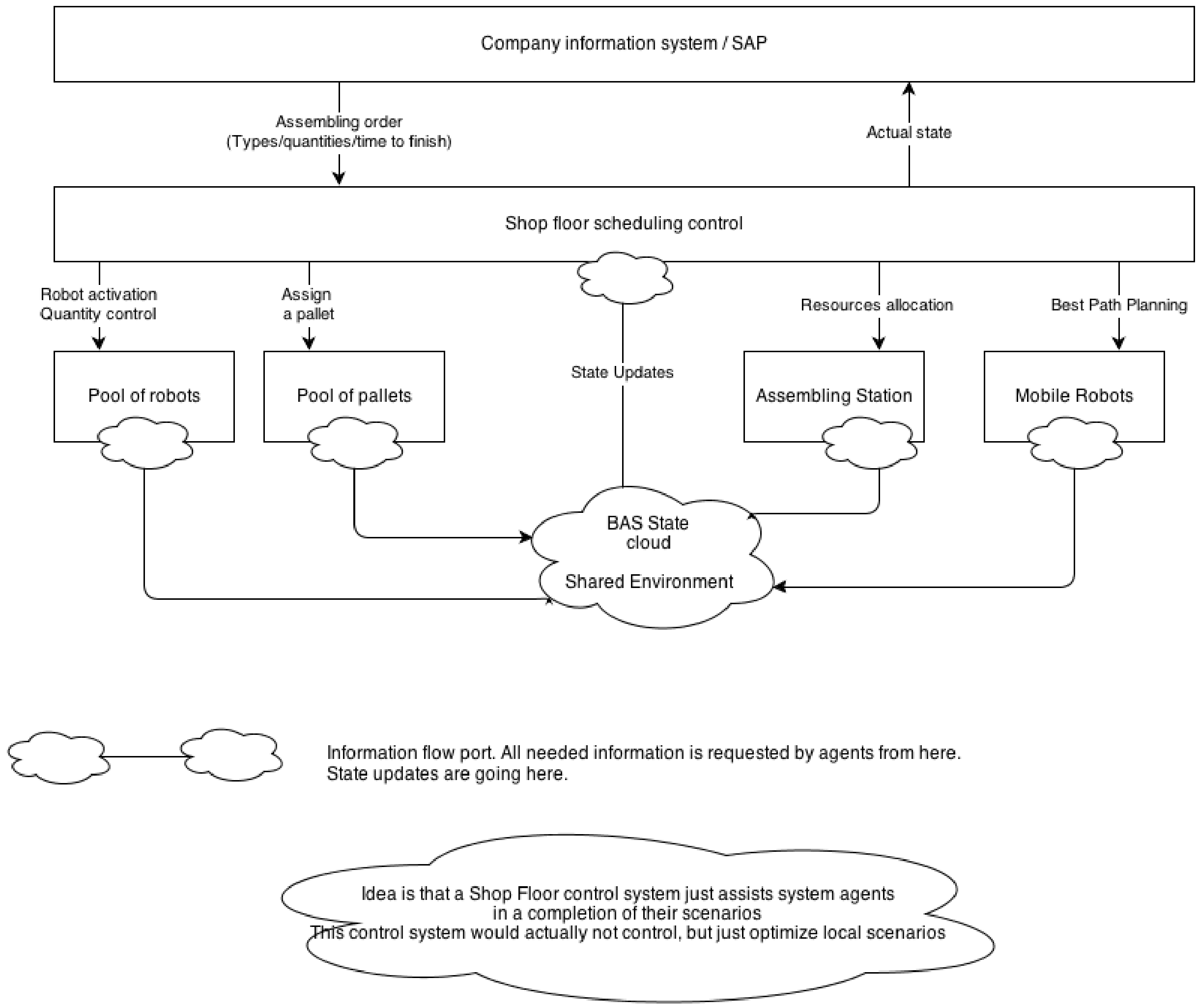


Fig. 12. Communication cloud in BAS

As a BAS is a part of a factory it is integrated to a ERP system of a company. Through a communication interface assembly order comes to a system. There are three components of an order, which are transferred from a system:

- type of product
- quantity
- time to finish

A system automatically assigns a product priority based on this data, and creates required amount of assembly orders. This information comes to a BAS state cloud, shared interface, which is securely backed up and connected wireless to all elements of a system.

A new assembly order is assigned to a pallet. Pallet is marked with a tag, and a product assembly file is created. Mobile robots, which monitors BAS state gets an alert, and goes to a pool of robots to take an assembly pallet. After a pallet is taken, robot sends an update to a cloud, and gets an assembly matrix. When robot gets a matrix, it sends a request to all the stations using the cloud. An information to be transmitted contains:

- Mobile Robot ID
- Order ID
- Current Assembly Step
- Current State(idle, moving, in a queue, assembly operation, quality failure, error)
- Last Station
- Next Station

Assembly stations use a cloud to provide an actual information to a mobile robots. A following data

Assembly Station Information

Ability and Time to Finish (Operation 51432 / 250sec && Operation 43456/350 sec)
Queue in front (R012/Priority 1, R123/Priority 2, R613/Priority 2)
Current State (idle, operation/time to finish, error)
Next element (Robot, error)
Coordinates (x,y, rotation)

A BAS state cloud helps to organize direct horizontal communication between BAS elements. This scheme is scalable and allows to include and take out system element without a interruption of working processes. Detailed description of BAS communication system will be published and presented in DAAAM 2013 conference.

6. Conclusion

The globalization gives the producers a new challenges, such as variable volumes and variety product types needed to be produced in one factory.

These factors together with development of transport and information systems give many possibilities for producers. Main one - to transfer the production to a developing countries to reduce a cost of production without the quality losses. This transfer causes in a significant reduction of a production volumes in a developed countries. Moreover, transferred technology will get a local development and improvement, and a connection with a developed countries could be totally lost. As an example we could see a case of Detroit, ex-capital of a world car manufacturing, where population decreased about 10 times, because of technologies transfers.

There is another type of the company development strategy - to create a new type of systems, which will be more effective to produce more on the same cost. This would give the same effect on a short run, but will give a company the advantages against the competitors in the future.

This system design concept helps to reduce the resources consumption, increase the utilization of machinery and makes the system more robust to a failure of one element. Research in this field would give the opportunities to make production more effective and profitable and avoid the technological transfers. This would give the opportunity to secure the production abilities in developed countries in a long run.

This report shows a part of a continuous research made by author and colleagues from IMS group of Vienna University of Technology. A mobile robot working algorithm, communication concept and system model were developed and presented in this paper. An axiomatic system design techniques gives a system a set of a structured requirements to be satisfied. This gives the system needed reconfigurability already on a level of planning. A next step of the research will be a performance comparison and a working mode test using a real production plant data.

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