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*Martin KRAJČOVIČ[*], Patrik GRZNÁR*

# UTILISATION OF EVOLUTION ALGORITHM IN PRODUCTION LAYOUT DESIGN

**Abstract**

*The need for flexibility of layout planning puts higher requirements for utilisation of layout and location problem solving methods. Classical methods, like linear programming, dynamic programming or conventional heuristics are being replaced by advanced evolutionary algorithms, which give better solutions to large-scale problems. One of these methods are also genetic algorithms. This article describes the genetic algorithm utilisation in the production layout planningunder the terms of the digital factory concept.*

## 1. REQUIREMENTS FOR THE PRODUCTION LAYOUT PLANNING

Current pressure on rapid innovations in the factory places increasing requirements also on the manufacturing and logistics systems design from the point of view of reduced laboriousness, consumption of time and costs for the whole system of technological design and, at the same time, on growth of quality, complexity and ability to testify the outputs generated from this process (Mičieta, Biňasová & Haluška, 2014).

Based on the mentioned reasons it is possible to sum up the following fundamental requirements on the process of technological design (Krajčovič, 2011):

- rapid design of new solutions,
- maintenance of systematic approach in design,
- manufacturing systems design as part of digital factory concept,

[*] Department of Industrial Engineering, Faculty of Mechanical Engineering, University of Zilina, Slovakia, e-mail: martin.krajcovic@fstroj.uniza.sk

- interactive design of a new manufacturing/logistics system,
- possibility of ongoing monitoring and assessment of proposed solution variants,
- implementation of optimisation approaches to design the time and spatial structure of the manufacturing system,
- proper visualisation and presentation of design outputs,
- possibility of dynamic verification of a proposed solution.

From the viewpoint of spatial arrangement of manufacturing and logistics structures, the following decision criteria are important (Krajčovič et al., 2013):

- minimisation of transport-related outputs and costs,
- minimisation of the areas needed,
- provision of occupational hygiene and safety,
- flexibility and the possibility of changes in the future,
- favourable conditions for team work,
- minimisation of reserves and continuous time,
- simple material flow,
- connection to an external logistics chain,
- possibility to flexibly optimise the arrangement in compliance with the changing production program.

## 2. APPROACH TO MANUFACTURING SYSTEMS DESIGN IN DIGITAL FACTORY CONCEPT

The design process itself has to respect the fundamental principles of the manufacturing systems design. With regard to the requirements for increase in the resultant design quality and decrease in the design time, it is necessary to enrich the classical approaches to the manufacturing and logistics systems with implementation of new progressive approaches and computer technologies (Li & Meerkov, 2009).

The process of manufacturing systems design has to run in the following phases (Fig. 1):

1. Preparation and analysis of input data: The basis resource of information needed for design is, first of all, the database from construction and technological preparation of production. Data for the manufacturing and logistics systems design can be divided into two basic groups:
   a) Numerical data – are used, first of all, to describe conditions in which the system will operate and are the basic input for output analyses of the manufacturing and logistics system. In compliance with a digital factory concept, numerical data are structured in three key areas (Hnát, 2012):
      - Information about products which will be made and transported in the manufacturing system (product types, piece lists, construction parameters, planned production volumes, etc.),

- Information about processes of their production (operations, manufacturing and assembling processes, used technologies, time norms, etc.),
- Information about resources for their manufacture (manufacturing machines and equipment, tools, workers, transport and handling machines, handling units, storage premises, etc.).

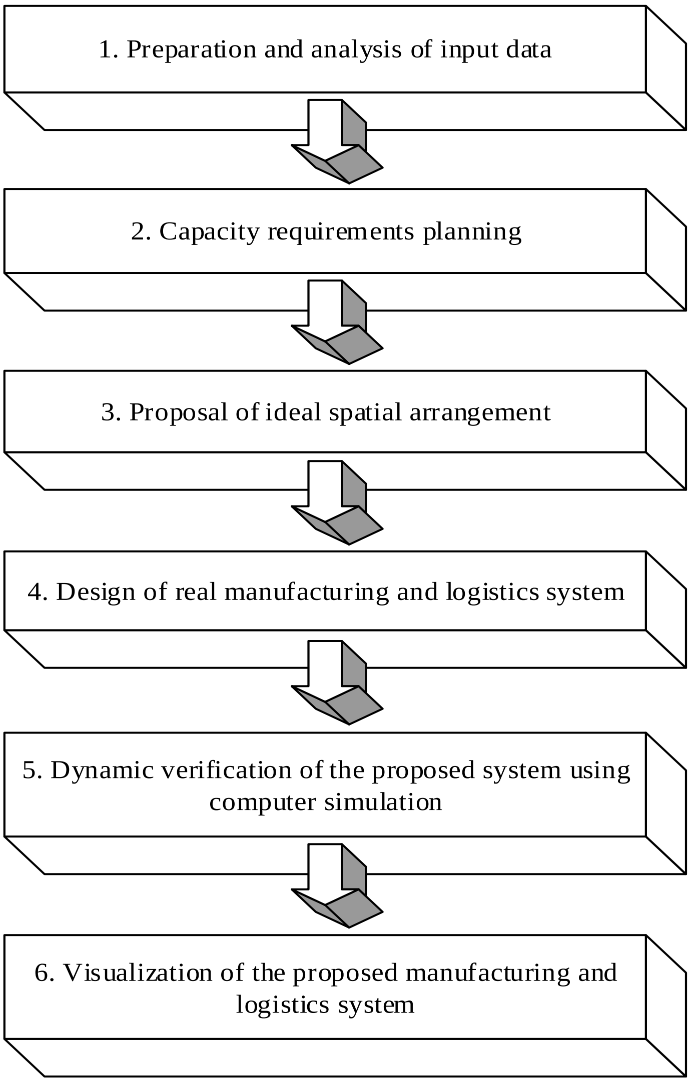
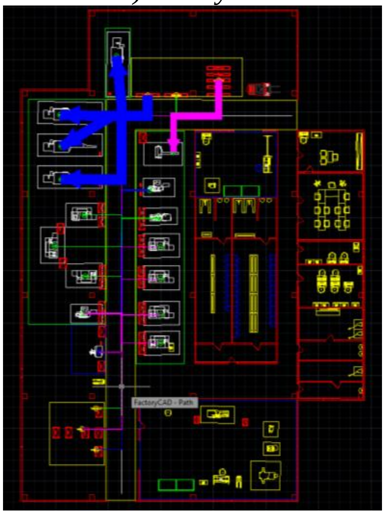



**Fig. 1. Methodology of manufacturing system design in digital factory concept**

b) Graphical data – represent visual display of individual elements of the manufacturing and logistics system which are used mainly in layout design and modelling and simulation of the resultant system (Furmann & Štefánik, 2011).

2. Capacity requirements planning: Before we start designing spatial solution of a manufacturing or logistics system, we have to decide which resources (production machines and equipment, transport, handling and storage devices, handling units, and the like), from the viewpoint of types and number, will be needed to ensure particular manufacturing and logistics processes in a designed system. Capacitance calculations serve this purpose. To calculate capacity needs, the designer has to know individual operations and activities of the manufacturing system, their quantity, time consumption norms for individual operations and available time for individual categories of resources (Ďurica et al., 2015).
3. Proposal of ideal spatial arrangement: When we know the need of individual resources of the designed system, material flows and other connections among individual elements, we can begin with designing an ideal spatial arrangement of the manufacturing or logistics system. In this phase of the proposal, no real spatial requirements of workplaces, no input-output places of the system and any other restrictions are considered (e.g. spatial restrictions). Proposing an ideal arrangement, it is advantageous to use optimisation methods and algorithms (graphical, analytical and heuristics methods). In this phase, evolutionary algorithms are also used (Hančinský & Krajčovič, 2014).
4. Design of real manufacturing and logistics system: Further stage of the solution of proposal layout of the manufacturing and logistics system is performed exclusively in a software environment (Fig. 2). Software environment for creation of real layout enables the designer, in a very short time, to verify more variants of detailed solution of either manufacturing or logistics system for which he uses tools for analysis, assessment and optimisation of the layout from the viewpoint of material flows and logistics (Dulina & Bartánusová, 2014). The designer can then make changes in the layout continuously; simultaneously with every change the designer receives the feedback about change of material flow parameters in the system, which enables him interactively and in a very short time to improve spatial arrangement of the designed system. Currently there are more software solutions and packets to support a 2D/3D design of layout solutions of manufacturing and logistics, e.g. VisTABLE, Factory CAD/FLOW, Autodesk Factory Design Suite, MALAGA, MPDS4 Factory Layout, EON Planner, etc.

*a) 2D layout*



*b) 3D model*

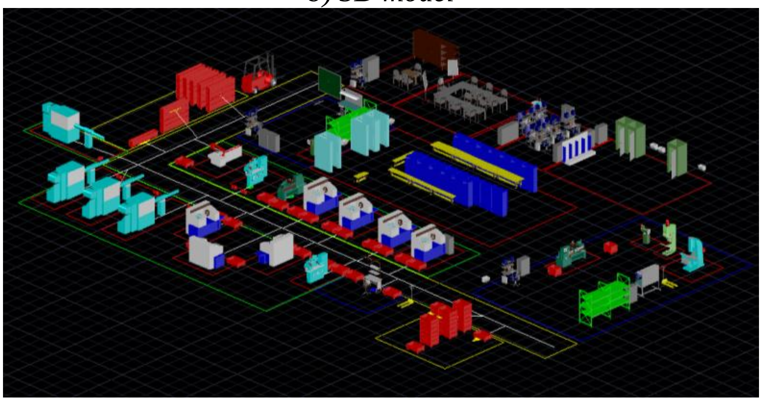


**Fig. 2. Example of real layout design in FactoryCAD/FLOW**

5. Dynamic verification of the proposed system using computer simulation: A lot of problems and risks occur at design and operation of complex manufacturing and logistics systems. Great numbers of variants and complexity of their assessment do not give a designer or manager a possibility to choose the best solution. These systems are commonly designed on the basis of narrowed views and criteria. It is just the modelling and simulation which provide the managers with a possibility of "dry run testing", how the proposed manufacturing and logistics system will operate and evaluate its optimality on the basis of costs and efficiency parameters (Trebuňa et al., 2014). The importance of simulation grows mostly with a growing system complexity. Computer simulation is in this case the only tool which allows,

also in complex systems, “a view to the future” with high accuracy and expressive power (Mičieta, Dulina & Malcho, 2005). The simulation application enables industrial factories to save a large sum of money. Great advantage is at present the strong software support for simulation of manufacturing and logistics systems (Arena, Simple++, Witness) and its integration into software solutions of the digital factory concept (DELMIA Quest, Tecnomatix Plant Simulation).

6. Visualization of the proposed manufacturing system: To meet the needs of a team proposal, visualisation and presentation of a layout plan for the manufacturing or logistics system design, it is appropriate to connect the software for the manufacturing and logistics systems design with the advanced hardware and software solutions, such as (Fig. 3):
   a) Planning table: This solution is suitable for a team proposal and optimisation of the layout plan and they simultaneously provide sufficient mobility of the system design. In combination with an additional data projector or monitor, it enables a parallel optimisation of the layout arrangement in a 2D display and visualisation of solution in 3D environment.
   b) Virtual reality (VR): Virtual reality is a type of human-computer interface that aims at creating the illusion of the user being immersed in a computer generated environment, providing a more direct communication link between users and the problem environment modelled by the computer system. In this case, designed manufacturing system is displayed using HMD (head mounted display) or CAVE (Computer assisted virtual environments) devices, fully in 3D environment (Strapek, Hořejší & Polcar, 2016).
   c) Augmented reality (AR): Research in the area of augmented reality focuses on development of technologies which allow the connection of digital content with real world in real time. In contrast to virtual reality which drags the user completely into synthetic environment, augmented reality enables to see three-dimensional virtual objects inserted into a real environment.

*a) planning table* *b) virtual reality* *c) augmented reality*

**Fig. 3. Forms of visualisation of designed manufacturing system**

## 3. GENETIC ALGORITHMS

Genetic algorithms are based on the principle of natural evolution, which was described in Darwin's book "On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life" (1859). In the seventies of the twentieth century, J. H. Holland proposed the idea of genetic algorithm as an abstraction of appropriate genetic processes (Saleh & Hussain, 2013). A decade later, genetic algorithms became one of major rapidly developing fields of informatics and artificial intelligence. Fig. 2 shows the basic procedure of genetic algorithm, which was divided into two main sections – evaluation and evolution (Misola & Navarro, 2013).

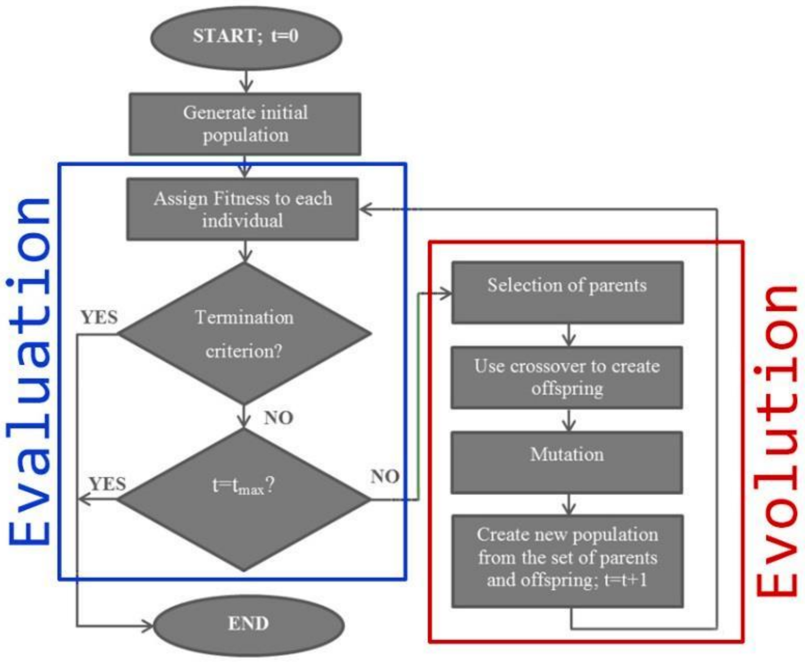



**Fig. 4. Genetic algorithm**

After generating the initial population, which can be created randomly, or based on historical/empirical data, the evaluation section takes place. The first step is to evaluate each individual in relation to the solved problem. Within genetic algorithms, we call the function that evaluates individuals as "fitness function". The basic principle of genetic algorithm is that individuals with better fitness must be unconditionally preferred in selection to next generation. However, with certain probability, it is possible for every solution to be selected. This ensures the diversity of the population.

The next steps after determining the fitness of all individuals in current population are two decision blocks, where the first evaluates, if the termination criterion is met (e.g. cost is below the specified value) and the second checks, if the maximum number of generations is not exceeded. If none of the above applies, the evolution section takes place. Within the evolution, the algorithm must first select the parents. As we mentioned, higher fitness means higher probability of individual being chosen. Several methods for choosing parents are known, we particularly can mention these(Yang et al., 2008):

- Roulette mechanism with fitness-proportionate selection,
- Roulette mechanism with rank selection,
- Stochastic universal sampling,
- Tournament mechanism,
- Elitism.

After determining the parents, genetic operators (Fig. 3) are applied, to create offspring. Crossover is an analogy to chromosomal recombination and reproduction in biology on which they are based. It is a genetic operator, which is responsible for mutual exchange of parts of chromosomes. Mutation is a genetic operator used to maintain genetic diversity of the population. Within mutation, one or more alleles in the chromosome are altered from their initial state. The main goal of mutation is to prevent algorithm from being stuck in the local extreme by preventing excessive similarity of individuals.

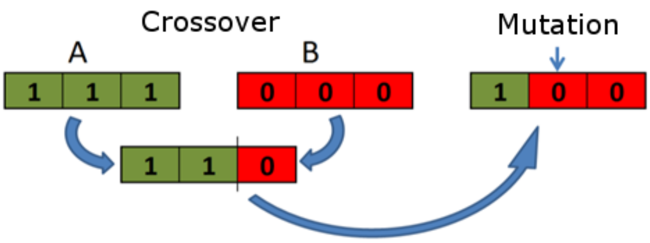



**Fig. 5. Genetic operators – crossover and mutation**

After application of genetic operators, new population is created, where both offspring and parents can be present, depending on the rules used within evolution. Subsequently, evaluation section calculates new fitness values and decides if another iterationis needed.

The main advantages of genetic algorithms include (Xu et al., 2011):

- They work with a population of possible solutions, thus it is less probable for the algorithm to end at a local optimum.
- They do not require any special knowledge about target function, they are universal.

- Genetic algorithms have very good results with problems with a large set of possible solutions.
- Versatility for a variety of optimisation problems.

Disadvantages include:

- They do not find optimal, but feasible solution.
- The implementation of the algorithm, the representation of solutions and the formulation of evaluation function can be difficult.

## 4. LAYOUT PLANNING USING GENETIC ALGORITHMS

Currently, system for plant layout design is being developed at the Department of Industrial Engineering at the University of Zilina, utilising genetic algorithms.

Own genetic algorithm for layout planning consist of (Fig. 4):

- specification of solution requirements and input data entry,
- layout optimisation (GA core),
- termination of the GA procedure (termination conditions).

At this stage, input and results are transferred between Matlab and Excel spreadsheet (Krajčovič & Hančinský, 2015), where simple user interface was created. In the spreadsheet, we input parameters such as number of machines, dimensions, types and probabilities of genetic operators or intensities between workstations/machines (Fig. 5).

After setting the input parameters we run the layout generator, coded in Matlab/GNU Octave language. The algorithm creates initial solutions in a specified quantity and performs evolution. The chromosome structure was determined as $2*n$, where $n$ is the number of machines. Therefore, we store information about X and Y coordinates of each machine inserted into the layout. Mechanisms for machine overlap correction and desired layout dimension maintenance were also incorporated. After the run, following data are transferred back to Excel (Fig. 6):

- X-Y coordinates of each machine,
- fitness value of proposed solution,
- graphic interpretation through block layout.

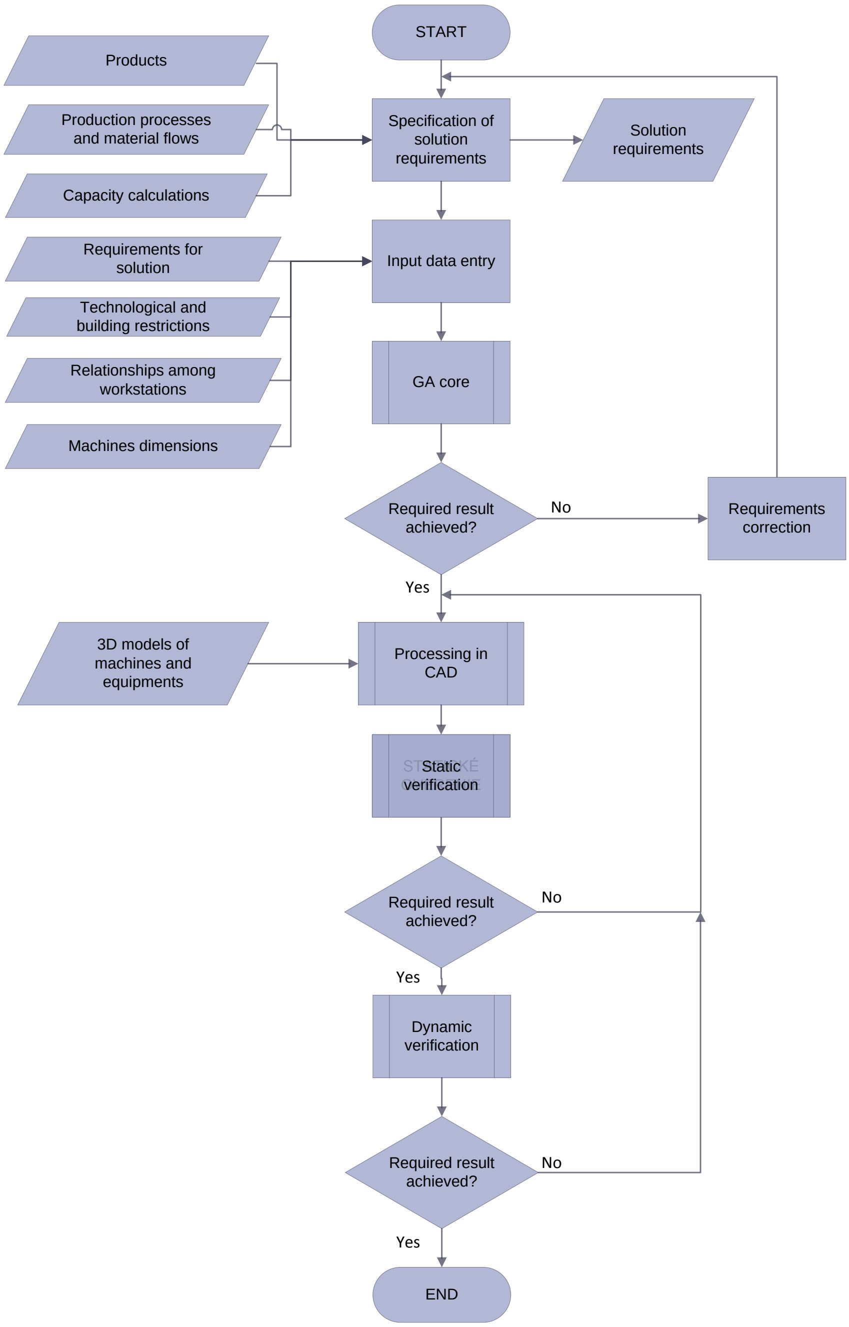



**Fig. 6. Procedure of production layout design using genetic algorithm**

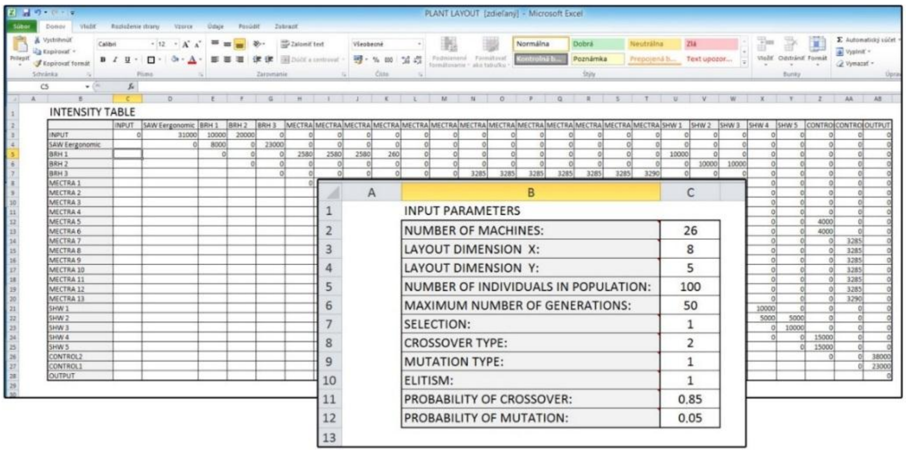
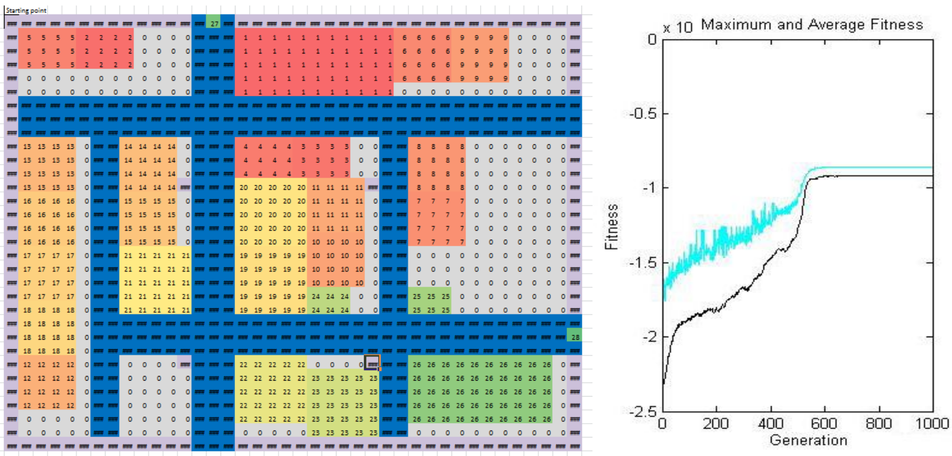



**Fig. 7. Input sections of spreadsheet**




*a) graphic interpretation (block layout)* *b) fitness value chart*

**Fig. 8. Results of genetic algorithm**

Block layout generated in Excel is converted to AutoCAD software (Fig. 7), where not only the obtained plant layout can be constructed, but also thanks to installed FactoryCAD/FactoryFLOW extensions, we can insert 3D models of machines in *.JT format, thus creating 3D model of machine layout and evaluate various aspects of the solution, such as material flow, aisle congestion, area structure or the possibility of milk run implementation with included tools. Also, thanks to SDX (Simulation Data eXchange) format, it is possible to evaluate obtained layout dynamically in another software solution by Siemens – Plant Simulation (Rakyta et al., 2016).

Thanks to these functionalities, we can not only get a possible layout solution, but also evaluate it both statically, and dynamically, which provides us with an advantage over solutions where only simple non-interactive block layout is created.

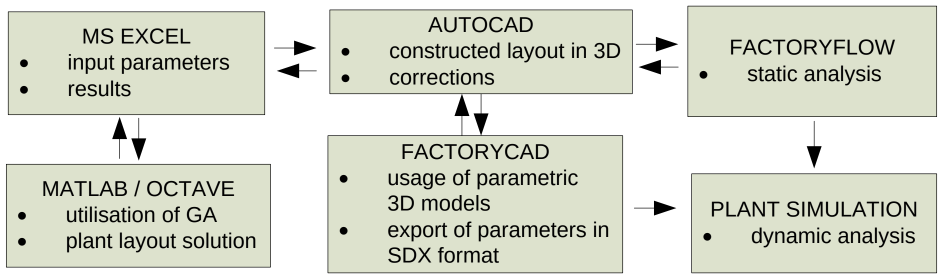



**Fig. 9. Proposed integration of plant layout design utilising genetic algorithms**

## 5. CONCLUSION

This paper describes the utilisation of genetic algorithm in the layout design of production systems. Authors' workplace addresses mentioned issues within the development of the digital factory concept and advanced industrial engineering methods (Altuntas & Selim, 2012). Described approach connects the algorithmic solution of the spatial arrangement problem (utilising genetic algorithms) with both static (FactoryFLOW) and dynamic (Plant Simulation) verification and also a graphical representation of the proposed production system (AutoCAD, FactoryCAD). The benefits of application of genetic algorithms are manifested mainly when solving large-scale problems of spatial arrangement, where genetic algorithms can effectively and more quickly converge to solution than traditional algorithms for spatial arrangement optimisation (Gašová, Gašo & Štefánik, 2017).

Described layout design procedure provides:

– Reduction of the time needed to design the spatial arrangement of the large-scale production system.
– Increase of the design quality through the implementation of appropriate configuration of boundary conditions to the algorithm,
– Complex verification of an obtained spatial arrangement solution through static and dynamic verification of the proposed system.
– Cost reduction in a designed production system.
– Visualisation of the spatial arrangement through a 3D model of the production system, which can be further presented and utilised with the use of progressive computer technologies, such as virtual and augmented reality.

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