Evolutionary strategies in agile facility design.

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Abstract:
Facility layout usually depends on products the facility manufactures and processes it performs. Nowadays market situation is volatile as customers' demands change more and more often. That is why the facility has to be agile to survive. Main characteristics of agility which are changing product mix, co-operation and interaction with customer in product development process and focusing on customers' requirements make agile facility layout design difficult. Designing facility layout for the manufacturing process which cannot be precisely formulated and is supposed to change is undoubtedly a specific problem. To solve this problem model of agile facility is to be introduced and evolutionary strategy is to be used.

Key words: agility, agile manufacturing, agile facility, evolutionary strategies, genetic algorithm, fuzzy agility index

Introduction.
According to Heidi and Alvin Toffler's theory civilisations grow and fall down like ocean waves and when one is still dominant the other is already existing and raising until it surpasses its predecessor.
The Tofflers claim that three civilisation waves have appeared as far:

- agricultural wave, represented by civilisation of farmers and craftsmen;
- industrial wave represented by factory workers and marked with mass migrations to the big cities;
- information wave – the civilisation of knowledge and computers development.

The next wave is believed to be the civilisation of individuals and individual attitude to life.
The Tofflers' theory clearly indicates the connections between civilisation and industry evolution. The idea of mass production was dominant in industrial wave, the FMS (Flexible Manufacturing Systems) conception was characteristic for the information wave. Thinking of the individuals' wave the question arises what the best conception for industry in forthcoming civilisation is. The most common opinion is **that agile manufacturing** is the answer.
This paper shows how to achieve agility and its main objective is to exhibit that agility not only can but should be achieved with suitable facility layout.
In proposed agile facility design procedure **evolutionary strategy** is to be used.
We are going to prove that designing facility layout is the problem which can be solved with genetic algorithms and a little of fuzzy theory and that the solution obtained with these tools is better than the one derived from traditional methods.

This work is organised as follows: in the first section the idea of agility is briefly described. The definitions of agile manufacturing are discussed and key words connected with the agility issue are explained. Section two introduces agile facility and its characteristics. It is strongly related to section one as the idea of agile facility is based on qualities and requirements of agile manufacturing conceptions shows the idea of agile facility and its characteristics. Section three describes the evolutionary strategies as nowadays they are the best way of dealing with complex facility layout problems. The next section presents the way evolutionary strategies are used in analysed FLP (Facility Layout Problem) which means it describes the AFD (Agile Facility Design) algorithm created to solve it. Section five is the example of AFD procedure usage and its results interpretation. The last section indicates difficulties, unsolved problems and unanswered questions connected with the research subject.

1. Agile Manufacturing.

With increasing pace of changes in customer demands, technologies and market environment a new strategy, new model of behaviour, becomes more and more indispensable for each company. Agile manufacturing is one of the approaches that can be applied to deal with foregoing challenges and difficult conditions successfully. The idea of agile manufacturing is one of the most recent conceptions in production management.
According to the Sandia National Laboratories [Emigh] common elements of agility are:

- changes in business, engineering and production practices,
- seamless information flow from design through production,
- integration of information technologies into product development and production,
- application of communications technologies to enable collaborative work among geographically dispersed product developments team members,
- introduction of flexible automation of production process.

According to Iacocca Institute **agile manufacturing** can be defined as *the ability to thrive and prosper in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer-based valuing of products*.
Speaking Julie Fraser's [4] words agility is the "ability to respond efficiently (doing it at the profit) to demand volatility" and according to David Mutch [7] manufacturing is "the art. of agility – the will, knowledge, and skill to continually reconfigure and integrate the processes of making things".

The most important characteristic of agile manufacturing than is the ability to adapt to the market situation by **co-operating** with customer and creating products he needs. It means that agile manufacturing is not about adapting to demands already existing on the market but accepting volatility of demands, creating and fulfilling them. That is why the key issue in agile establishing is the customer and keeping him involved in the process of product creation. **Interaction** between customer and manufacturer is important because agile manufacturing is manufacturing of individual, unique products. Being aware of customers needs and requirements and on the other hand of the restraints of technology and production process leads to creating the perfect product for both the customer and the manufacturer. Such interaction requires the **communication** between all the production process performers. Nowadays products are not necessarily developed in one place, so creating solid formal structures is not possible. The solution is organising **virtual teams** which are to be responsible for one product and reorganising them after the product is finished. The only tool which can assure fast, continuous and easy communication is the internet (agile manufacturing uses the information technology, intranets and extranets so it is sometimes called e-manufacturing). Controlling virtual teams requires good **co-ordination** of information and responsibility flows between all the members of the production process. Multi-skilled virtual teams are able to develop new product in a very short time which makes agile manufacturing **flexible**, **innovative** and results in a very short **response time**. Organising virtual teams is also the crucial element of **manufacturing synchronisation,** getting the right product to the right person at the right time thanks to treating the production process as a whole and dynamic assignment of resources to tasks and tasks to the resources.

The conclusion from agility conception above outspread is that the characteristics of agile manufacturing are following:

- manufacturing synchronisation,
- short response time,
- flexibility,
- innovation,
- virtual teams,
- communication,
- co-ordination,
- interaction,
- co-operation.

Possessing the qualities mentioned above leads to agility and lets achieve the aim of agile manufacturing which is to fulfil customer's requirements and thanks to that gain the profit for a company.

2. Agile Facility.

The issues relatively neglected are the ways of achieving agility, especially the layout for agile manufacturing problem.
As the facility layout has considerable influence on production process characteristics it is essential for gaining agility. Of course if company wants to benefit from practical application of agile conception it should possess all the features mentioned in previous section.
Synchronisation, co-operation, communication, co-operation, co-ordination and interaction are the matter of proper operational management. They can be achieved thanks to *virtual teams* and applying them leads to *short response time*.
Flexibility is dependent on machines performing the production process and the facility layout.
Synchronisation and flexibility are the main qualities of product - focused production based on Just-in-Time system but applying JIT to agile manufacturing is impossible because of product orientation of JIT system.
Agile manufacturing is typical process focused manufacturing conception as products manufactured are various and usually unique. Combining characteristics of process oriented manufacturing with synchronisation and flexibility leads to following model of agile facility layout:

1) agile facility comprises of two kinds of units:
   - flexible manufacturing units, technologically specialised, which perform the most labour-consuming stages of a production process,
   - universal machines to perform the other stages of a production process.
2) flexible manufacturing units are allocated in central part of a facility,
3) universal units are allocated on its perimeter,
4) input and output to the manufacturing process are located on the opposite sides of agile facility.

The scheme of the agile facility is shown on the figure 1. The shape of facility on the scheme is rectangular, which is most common instance. The idea of agile machine placement can also be used in facilities with the irregular floor – shape as the most important is the relation between the external universal machines and the internal specialised ones.

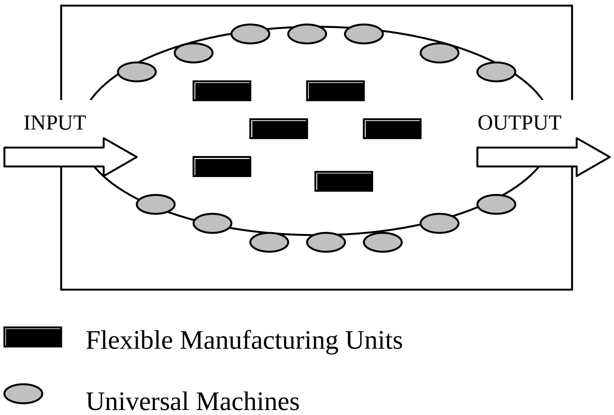


Figure 1. The agile facility layout.

Allocating universal machines depends on their quantity and is homogeneous, allocation of flexible manufacturing units is the result of function optimisation. After analysing different methods of function optimising (mathematical, heuristics and meta-heuristics) in the aspect of their usefulness to the agile facility layout we decided to apply Evolutionary Strategy (from the meta-heuristics group) as it allows to solve complex FL (Facility Layout) problems relatively quickly and at low cost.

3. Evolutionary strategies.

Evolutionary strategies are the AI methods of optimising functions by imitating the natural selection and biological evolutionary process in order to achieve the best solution of a problem according to the rule “the best survives”. They combine randomised search and stochastic heuristic.

Genetic algorithms are the kind of evolutionary strategies which uses traditional binary chromosome (encoded solution) representation. Evolutionary strategies use numbers and letters to encode the solution. The second difference is the way of selecting solutions to survive. Evolutionary strategies bring up the next generation in a deterministic way by creating a population of all the parents and their children and eliminating the individuals with the lowest fitness values to make a new generation. Genetic algorithms’ way of creating new population is more stochastic though based on the fitness function value. The third difference is the order of stages: in evolutionary strategies genetic operations are to be used before the selection, in genetic algorithms selection is followed by genetic operations.

This division is not always taken into consideration and methods with both types of chromosomes are called genetic algorithms.

According to Rajasekharan et al.[8] “a genetic algorithm maintains a collection or population of solution throughout the search. It initialises the population with a pool of potential solutions to the problem and seeks to produce better solution (individuals) by combining the better of existing ones through the use of one or more genetic operators”. The very first step in performing GA search is choosing the initial population of solution, evaluating their fitness and choosing the best individuals for reproduction. **Selection** is the operation which makes chromosome with higher fitness survive to the next generation. One of the approaches to selection process is the ‘tournament selection’. The size of the tournament is the number of solution competing. The chromosome with the highest fitness value is the winner and he is picked up for reproduction. The other approach to the selection is a ‘roulette wheel’ based choice.

Reproduction is creating new individuals using genetic operators. The genetic operators most often used are:

- **crossover** – there are different types of crossover f.ex. PMX (partially matched crossover), OX (order crossover), CX (cycle crossover)
- **mutation –** for example random altering, inverting, swapping, mutation is performed on some chromosome, depending on ratio chosen.

The new individuals are added to population and evaluated. The chromosomes not chosen to reproduction are excluded from the population and the number of population is fixed. The loop is ran until the expected **fitness** value is achieved for at least one chromosome.

The evolutionary strategies start with the reproduction process which is followed by the selection. As mentioned above the selection is based only on the fitness value of individuals.

Both evolutionary strategies and GAs can be applied in numerous areas, depending on user’s data and knowledge. FLP (Facility Layout Problem) is one of the applications of GAs, giving good results in relatively short time and generating relatively low cost.

4. Agile Facility Layout Design Procedure.

Evolutionary strategy applied to agile facility layout procedure is performed on population of solutions which are random facility layouts. It uses basic genetic operations i.e. crossover and mutation to produce children - new layouts. The offspring’s fitness is evaluated and solutions with the best fitness value are joined to the next generation. The scheme is repeated until the expected fitness is obtained for at least one solution as it is shown on Figure 2. This solution is to be the final facility layout.

Initial population

The problem we are working at comprises forty groups of machines used in a production process of tractors.

Initial population in our project is one hundred of random solutions derived from a sequence of machine groups permutation.
The size of population depends on a project and its complexity. We decided to settle the number of initial solutions at the level of maximum quantity of populations.

Optimisation criteria.
The optimisation criteria applied in the project are time, cost, distance and ratio of these factors and their wages. The idea is to analyse the difference between the solution chosen for its best, which is shortest, time, the lowest cost and the shortest distance as well as the one with the best value of three waged factors combined.
Waging factors is justified by their importance for achieving agility. According to that criteria the less important is cost and the most important is time.

Evaluating fitness value.
The procedure of evaluating fitness value is shown is shown on Figure 3.

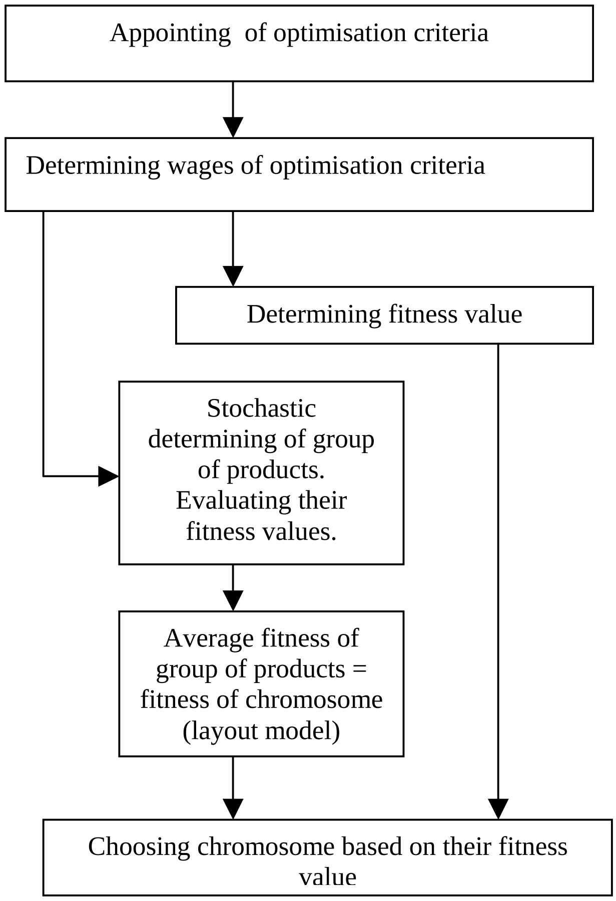


Figure 3. Evaluation of solution's fitness value.

Evaluating fitness value during the research phase we are in consist of evaluating cost, time, distance and mix of all these criteria for each solution.
The essential problem in agile facility design is the data to use. We assume the branch of facility is known and technological data for group of products in that branch are available. The data covering cost, time and distance come from a group of products (we have decided to take five products for each calculation) determined stochastically from typical products of the designed facility's branch.
To evaluate fitness values of solutions generated by genetic algorithm cost, time, distance and mix of all these criteria is evaluated for group of products chosen. The calculations are based on technological processes of the products.
Final fitness of solution is an average fitness obtained.

Encoding solutions.
The way of encoding solutions differs on account of the problem to be solved. The problem analysed in this project comprises forty machine groups, the quantity of machines in each group is predefined. These groups are to be divided into two sets:

- the set of highly specialised groups;
- the set of universal groups.

The set of universal groups is to be placed along the perimeter of a facility.
The set of highly specialised groups is to be allocated using the GAs.
Each of the specialised groups has its code which is the letter, each string of letters makes chromosome.

Selection.
Selection is based on a fitness value. Solutions with the best fitness value are to survive.
The most popular mechanisms of selection are the tournament and the roulette wheel. Both of them are used in this project and the question is to check whether They have any influence on the quality of solution finally obtained.
The stochastic mechanisms of selection are used before the first run of reproduction.
The deterministic mechanism of selection is used after the reproduction stage to create new generation.

Crossover.
The crossover is one of the genetic operators used in both evolutionary strategies and GAs.
The crossover applied in our project is one point order crossover.
The point of crossing is chosen randomly for each solution.
For a pair of parent chromosomes:

ADGEFCHB
ABCDEFGH

And crossing point i=3 the crossing operation runs as follows:

ADGEEFGH
ABCDFCHB

The crossover is performed with predefined crossover probability.

Mutation.
Mutation is the genetic operator which is a kind of self crossover.
It is an exchange of genes symbolised by letters and it takes place in one chromosome area.

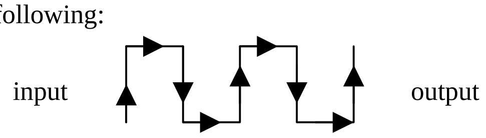
ADGEEFGH
AGDEEFGH

The mutation is performed with predefined mutation probability.

Repairing Chromosomes.
After crossover and mutation some of the chromosomes may be damaged. The damages are double letters which mean that some of machine groups are to multiply and some of them to disappear.
Repairing procedure's job is to detect double and zero letters and to replace every second letter with missing one.
The result of running the repairing procedure for the chromosomes from previous paragraphs are supposed to be following:

AGDEBFCH
ABCDFEHG

Decoding solutions.
The order of letters in chromosome determines the order of allocating machine groups through the facility area.
The pattern of allocating objects used in our project is following:



The number of machine of machines to place in each row is dependent on the size of the facility floor and the quantity of machines to place as well as their sizes.
After the decoding solution is ready be used or checked.

Adding new solution to the population.
This part of a procedure is in fact making a new generation.
Children and parents with the best fitness values are to survive and make a new generation.

Loop until the expected fitness is achieved.
The expected fitness value for our project is half the time, the same cost and three forth of distance achieved in conventional solution. Of course each of these ratios is likely to be changed during the research and the influence of changes made is to be analysed.
In case of not achieving presumed level of fitness factors values the procedure stops after predefined number of runs.

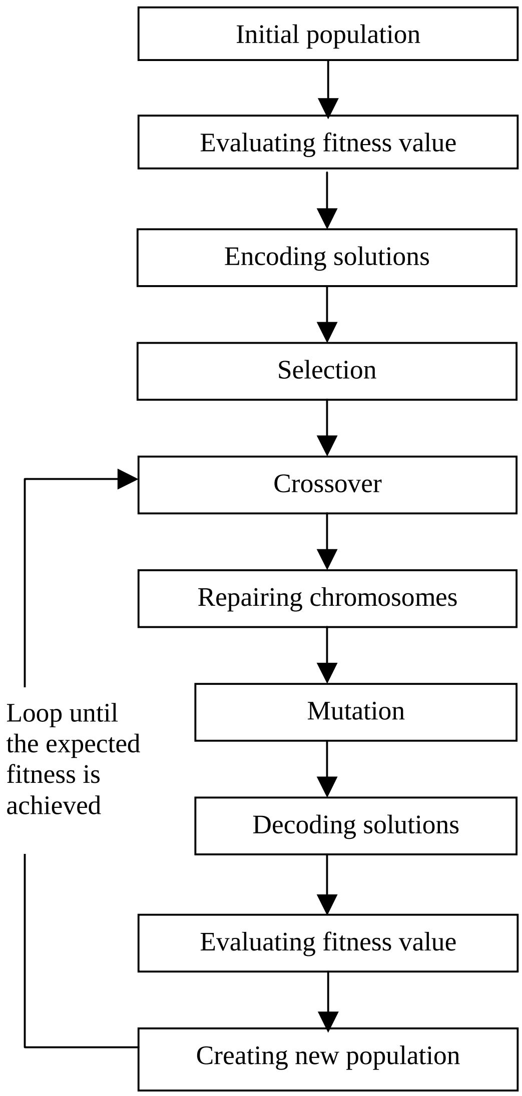


Figure 2. AFL genetic algorithm

The evolutionary strategy used in Agile Facility Design procedure can be divided into two phases: first one is an initial phase in which the initial population is randomly created, its fitness is evaluated, then it is encoded and individuals for reproduction are chosen.
The second phase is growing the best solution which is reproducing, evaluating and selecting the individuals to the next generation. Selection in this phase is hidden in a creating new generation stage and is based on a fitness value of individuals evaluated.
The second phase leads to reaching the best solution.

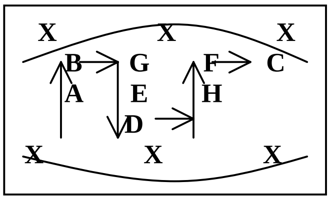
5. The Example of AFD procedure.

The data used in our project comprise data connected with machines, products and parts they are composed of. The problem solved in our project is complex and considering its size we decided to show the idea of AFD by presenting simplified example.
As the part of AFD procedure which performs genetic operations is quite simple and universal it does not require more detailed explanations. However we would like to show some details connected with the fitness evaluating part. The size and the length of presented example make it easy to analyse and comment.

Data to use in the example are following:
Number of groups of machines to allocate = 8
Number of parts to evaluate fitness value = 3
Chromosome obtained as the best solution:

ABGEDHFC

Number of universal machine groups = 6
Allocation of machine groups on the facility floor::



Fitness of this solution is the result of calculations based on characteristics of random parts' technological processes.

	Op1.	Op2.	Op3.	Op4.	Op5.	Sum:
Machine group	B	G	X	G	E	
Time	20 tu	20 tu	40 tu	20tu	50 tu	150
Time tr	5 tu	5 tu	5 tu	5 tu		20
Cost	80cu	60cu	40cu	60cu	50cu	290
Cost tr	5cu	5cu	5cu	5cu		20
Distance	10du	10du	10du	10du		40

Table1. Part A.

	Op1.	Op2.	Op3.	Op4.	Op5.	Sum:
Machine group	A	E	D	X	H	
Time	50tu	50tu	20tu	40tu	80tu	240
Time tr	5tu	5tu	5tu	5tu		20
Cost	100cu	50cu	120cu	40cu	60cu	370
Cost tr	5cu	5cu	5cu	5cu		20
distance	10du	10du	10du	10du		40du

Table2. Part B.

	Op1.	Op2.	Op3.	Op4.	Op5.	Sum:
Machine group	B	E	X	F	C	
Time	20tu	50cu	40tu	100tu	45tu	
Time tr	5tu	10tu	5tu	5tu		25
Cost	80cu	80cu	40cu	100cu	90cu	
Cost tr	5cu	10cu	5cu	5cu		25
distance	10du	20du	10du	10du		50du

Table3. Part C.

Note: Measures used to characterise cost, time and distance of production process of analysed details are adequately: cost unit, time unit and distance unit

Summing up the data from tables above:

	time	Cost	distance
partA	310	170	40
partB	390	240	40
partC	385	280	50
average	361.7	230	43.3

Table4. Cost, time and distance of final solution.

According to agile manufacturing characteristics its most important feature is time, followed by distance. The cost factor is the least important of considered threesome.
That is why the weights given are following:
Time = 0.5;
Distance = 0.3;
Cost = 0.2;
Which makes the final value of 'mixed fitness' function:

$$F = 200.33$$

All the values calculated in analysed example are taken into consideration while evaluating fitness and quality of solutions.

The reproduction process is being continued until time/cost/distance values reach the expected values.

Conclusions.

The evolutionary strategies are very useful in solving FLPs (Facility Layout Problems) because they are easy to use, cheap and fast.

Our research is still in progress and we are exploiting the possibilities given by ES and looking for its advantages and disadvantages. To make the evaluation of ES reliable, the solution obtained by evolution process should be compared with the solution derived from another method of solving FLPs. Therefore the last part of our project is comparison between layout obtained with using evolutionary strategies (ES) with the one acquired by traditional heuristics for facility layout planning.

We decided that comparing the layout obtained with ES and the one based on traditional heuristic cannot be based on cost they are generating. The time of processes performed and distance the parts are to go while being worked at are not the appropriate measures neither.

As the main aim of a project to design the agile facility the agility of both of the solution is to be measured and evaluated. The tool used for evaluating the agility is the Agility Index. Due to agility features it is impossible to measure with numbers and traditional ratings. Measures for communication, interaction e.t.c. are described with linguistic terms which makes fuzzy logic indispensable in agility measuring [11]. The Fuzzy Agility Index (FAI) developed by Ching-Torng Lin is based on customer sensitivity, collaborative relationship, process and information integration. Attributes of these dimensions are assessed and weighted by experts, then fuzzy ratings and weights are aggregated into FAI. Analysing the results of assessment helps to measure the agility and shows the way to agility either.

We would like to use FAI to measure the agility of layout analysed and compared but the dimensions to be exploited are not defined yet. Thus we believe that only comparing traditional and agile facility by measuring their agility can show whether the project we are working at was successful or not.

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