

# Optimization of the Plant Layout in the Production of the Special Transformers - Case Study

**Damir Belic**

Assistant  
University of Zagreb  
Faculty of Mechanical Engineering and  
Naval Architecture  
Croatia

**Zoran Kunica**

Professor  
University of Zagreb  
Faculty of Mechanical Engineering and  
Naval Architecture  
Croatia

**Tihomir Opetuk**

Postdoctoral researcher  
University of Zagreb  
Faculty of Mechanical Engineering and  
Naval Architecture  
Croatia

**Goran Dukic**

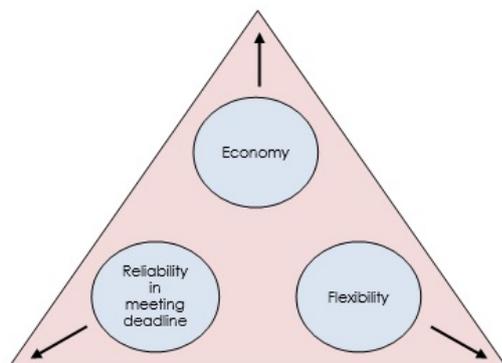
Professor  
University of Zagreb  
Faculty of Mechanical Engineering and  
Naval Architecture  
Croatia

*This paper is a case study of the plant layout optimization in the production of the special transformers. The continuous global crisis is an ideal time for companies to raise their efficiency, flexibility and transparency of their operations and competitiveness in the global market. One of the possibilities to improve these features is a reduction of internal transport costs, based on the utilization of the company's own resources. With optimal layout of the workplaces and the equipment, the transport routes are shortened, thereby the employees' time is reduced, transport means are released, production lead times are shortened and intermediate warehouses are reduced or closed. Because the employees' time is reduced, they have more time to do something effective - what the buyer is willing to pay for. Also, with shorter production lead times, there is a faster material flow, less waiting and less opportunity cost of capital. The paper shows the steps that are necessary for the transition from the existing to the optimal layout of workspaces and equipment. Bloch-Schmigalla triangular method is used for the optimization.*

**Keywords:** intralogistics, material handling, routing, triangular method, performance analysis.

## 1. INTRODUCTION

In an ever more globalized world, manufacturing enterprises are facing growing challenges in terms of competition, volatile markets and a turbulent environment [1]. At a time of rising costs, time pressures in production and globalization in general, plant layout and logistics are among the key factors for the success of the company [2]. If the company wants to stay competitive it must continuously increase its efficiency on all fields of manufacturing [3]. Nowadays, the three most important characteristics of a company are: economy, reliability in meeting the deadlines, and flexibility (Figure 1.) [4].



**Figure 1. Main characteristics of a manufacturing company [4]**

Unfortunately, these three characteristics are contradictory. The higher the reliability of deadlines and flexibility are, the more difficult is economical production at a fixed price. On the other hand, if the company economy is the most important characteristic, then it is difficult to meet the deadlines and to be flexible. The next important characteristic is to be up-to-date. If a company does not use IT-supported data acquisition, then the data are not up to date. Also, due to the reduction of product life cycles and the fast changing global demands, production and factory planning cycles become shorter. Agile enterprise structures are necessary to manage ongoing changes [5].

Because of all mentioned above, the company must operate fast under a new scenario and needs to have a review of the current situation about [4]:

- where and what is going on,
- where the problems occurred,
- where the delays occurred,
- what functioned better than planned.

At every moment, the company knows its status regarding capacities, materials and costs. Consequently it is possible to make new plans quickly, taking into account customer satisfaction and economy.

The paper shows the steps that are necessary for the transition from the existing to the optimal layout of workspaces and equipment. Bloch-Schmigalla triangular method is used for the optimization.

## 2. PLANT LAYOUT OPTIMIZATION

Spending a little time to plan the arrangement before installation can prevent unnecessary losses [6, 7]. Planning the production plant layout at the outset before building the plant or office is the best way to reduce the

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Correspondence to: Damir Belic  
University of Zagreb, Faculty of Mechanical  
Engineering and Naval Architecture, Zagreb, Croatia  
E-mail: dbelic@fsb.hr

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costs remarkably. Manufacturing products or delivering services at high quality, with less cost and in short time using the fewest resources is the objective of properly managing a facility [6, 8]. It is important that the facilities must be managed properly in order to attain the objective. Also it is necessary to optimize a production plant layout in existing factory, if the layout isn't designed correctly.

There are many procedures and algorithms that can assist facility planners to construct the new layout or improve the current layout such as: Systematic Layout Planning (SLP), Pairwise Exchange Method (PEM), Graph Based Theory (GBT), Dimensionless Block Diagram (DBD), Total Closeness Rating (TCR), Bloch-Schmigalla triangular method, etc [9].

On the basis of research [4, 10, 11] a conclusion was done that the optimization of layout of production means can be carried out in four steps:

- Step 1: Description of the manufacturing process,
- Step 2: Creation of the material flow intensity matrix,
- Step 3: Description of the existing layout of production means in the company,
- Step 4: Proposal of the improved layout of production means in the company.

In this case study, the Bloch-Schmigalla triangular method is used for the layout optimization of the existing production plant.

### 3. DESCRIPTION OF THE EXISTING LAYOUT

Special transformers and reactors for medium voltages produced by Končar D&ST (Distribution and Special Transformers) have a long tradition and are well known worldwide for number of years. Production program of special transformers is produced in a separate production hall, where each process is organized especially for the assembly of special transformers - from separate hot air drying plants, winding machines and oil purification machines for several oil types (including mineral oil, synthetic organic ester, silicon and vegetable oil) [12].

Simplified flow chart of transformer production is shown in Figure 2.

In the current production hall there are four machines for winding different types of wires (workstations 1 to 4), two dryers (dryer of the active part and the electrical dryer), control station and a space for external oil filling and assembling of active parts and final assembling. Figure 3 shows 2D layout of the production hall. Blue circuits are representing Workstations 1 to 4, and transport routes are marked by yellow lines. Following the simplified flow chart, this production hall is suitable for making every step in this chart except cutting and stacking a core. Cores are cut and stacked in the separate production hall and they are transported to the place suitable for assembling of the active part in this production hall.

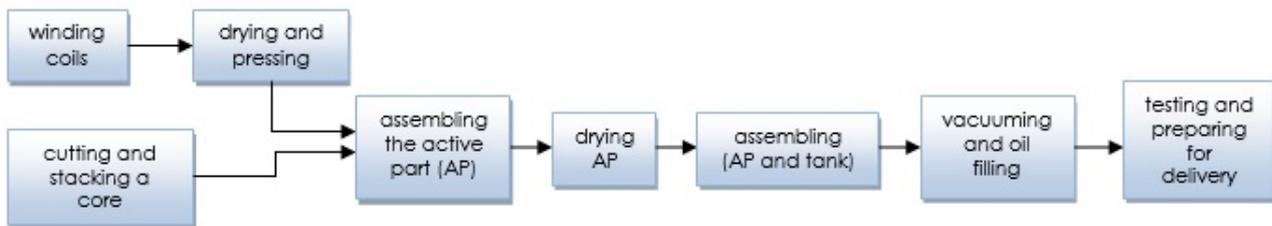


Figure 2. Simplified flow chart of the transformer production

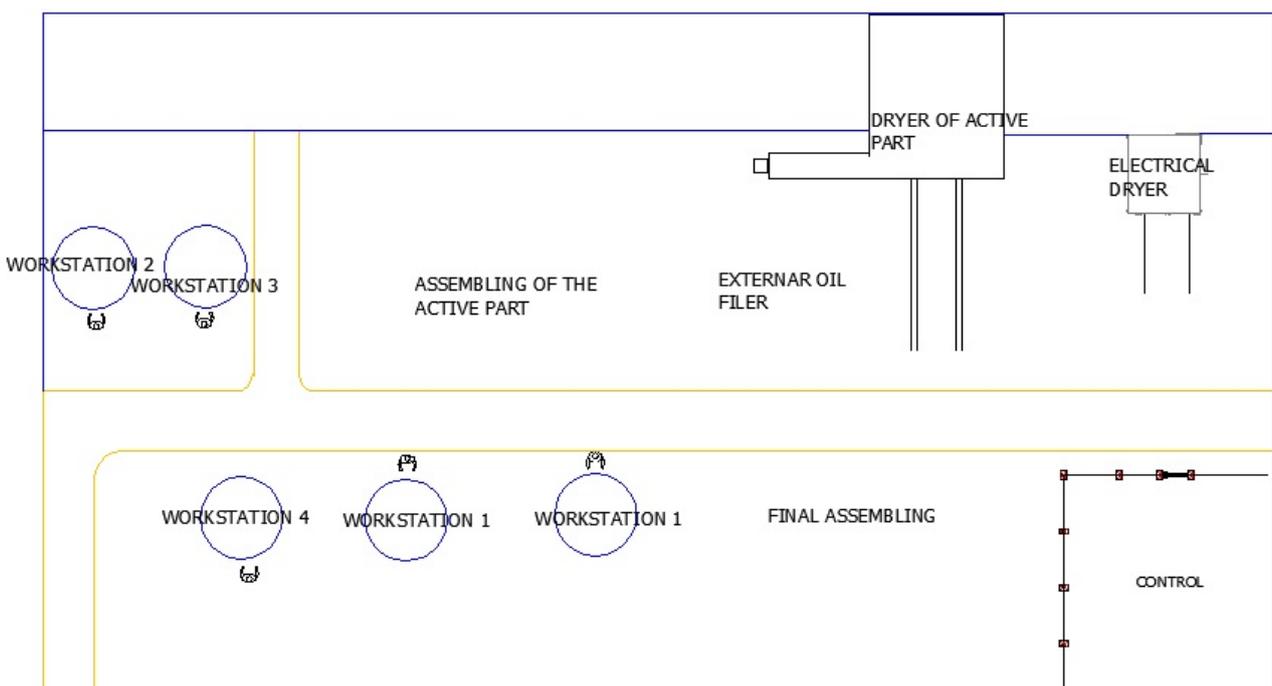


Figure 3. Layout of the production hall

#### 4. OPTIMIZATION OF THE SYSTEM LAYOUT

The goal of the system optimization is to get the optimal layout of the elements in that system. Positioning of the elements is based on the material flow. There are two criteria for layout optimization. First criteria are based on the optimization of material flow direction (the goal is to ensure that the material flow is as linear as it can be). Second criteria are based on minimization of transport distance (total transport intensity). Total transport intensity is a product of the material flow intensity and the distance between the elements.

In this paper the Bloch-Schmigalla triangular method is used for optimization of the material flow. The triangular method was developed in 1950. by Bloch. The goal is to arrange the elements by the criteria of minimum transport distance. Bloch's method is based on these several principles:

- If the connection between two elements in the system is needed (the elements are connected by some sort of transport), the optimal way to do that is to set both elements in terminal positions of the base line.
- If the connection between three elements is needed (the elements are connected by some sort of transport), the shortest way is to put them in the vertices of equilateral triangle.
- The fourth element in the system can be put somewhere on the three possible locations of the adjacent equilateral triangles, which result the minimum transport cost, etc.

The disadvantage of Bloch's triangular method is that the method does not give the answer to which elements should be placed first in the mesh of equilateral triangles. H. Schmigalla improved Bloch's method and named that improved method the modified triangle method [13]. The method is extremely useful when designing new production systems or when analyzing the existing ones that are confronted with changes during the production process or during the process of optimisation of the current layer state. The goal and the result of the method are to get the minimum transport output:

$$f_c = \sum_{k=1}^m \sum_{j=1}^m b_{kj} \times s_{kj} \rightarrow \min \quad (1)$$

The least possible value of  $f_c$  means that the elements in the system are placed in a way which ensures optimum flow of the material [14]. The starting hypothesis of Schmigalla method is that the minimum transport output will be achieved if the elements with the largest intensity of material flow are set next to each other in the triangular mesh. If there are more than one such pair, the one having the highest number of connections with the other object is selected. If there is still more than one such pair of objects, then a random pair is selected and placed in the neighbourhood vertices of the central equilateral triangle of the mesh. Next, the sum of the intensity of connections between dislocated and not dislocated objects is determined. Between non dislocated objects, the one having the highest intensity of connections with the dislocated object is selected and placed next to the first pair in the mesh. If it turns out

there is more than one object with the same highest number of connections with the dislocated object, a random one is selected. After the selection of the subsequent object is located, its potential position in the triangular network is determined [15].

There are a few main disadvantages in the modified triangle method. Although the procedure of calculating, selecting and placing elements in equilateral triangle mesh is relatively simple for low numbers of elements, it becomes much more complex and time-consuming if there are more than ten elements in the system. The second problem is the fact that the degrees of material flow, and sums between elements which are not yet placed and the pairs of already placed elements, start to repeat themselves. When selecting a new element for placing in the triangular mesh, several possibilities can emerge. This means there are more options for building a layout. There can be more than one candidate to be selected next or/and there are several possibilities regarding already emerged pairs where new candidate can be placed. Depending on the complexity of the model and connectivity between the elements, finding the optimal solution can be extremely difficult to solve. Nowadays there are many generic algorithms for solving the facility layout problems such as one presented in [16].

In this case, a study of the analysis of the existing layout system is given to check the suitability of the current arrangement in relation to the ideal. In addition to analysing the current situation, the proposals of the new optimal layout system is given according to the results obtained by the modified triangle method.

The starting point of the analysis is the calculation of the material flow intensity matrix. The calculation of the flow is based on the data of production program, development plans and assembly plans. Also the description of manufacturing program is given by the company, so the calculation is given by analyzing the fourteen representative products (divided into three groups: dry transformers and two groups of special transformers). The calculation is made by following these steps [14]:

- The product is divided into smaller sections (assemblies and parts),
- Number of parts and assemblies are defined for planning period (eg. month, year etc.),
- Material handling equipment for each component is defined.
- For each component the necessary number of transport is calculated. Number of transports for one series of one component is calculated by this formula:

$$n_{Oli} = \frac{Q_{si}}{Q_{POi}} \times \frac{1}{Q_{TSi}} \quad (2)$$

- The material flow intensity, expressed in the number of transports between k-th and j-th element of the system in the planning period is calculated (number of transports multiplicities the number of series).
- Total transport intensity in the planning period between k-th and j-th element of the system is obtained by summing the transport intensity for all the components which are transported between the elements of the system.

TO \ FROM	WORKSTATION 1	WORKSTATION 2	WORKSTATION 3	WORKSTATION 4	ASSEMBLING OF ACTIVE PART	DRYER OF ACTIVE PART	ELECTRICAL DRYER	FINAL ASSEMBLING	CONTROL	EXTERNAL OIL FILLER
1. WORKSTATION 1					16					
2. WORKSTATION 2					14					
3. WORKSTATION 3										
4. WORKSTATION 4					16					
5. ASSEMBLING OF ACTIVE PART							100		160	
6. DRYER OF ACTIVE PART								62	62	
7. ELECTRICAL DRYER									60	
8. FINAL ASSEMBLING									103	15
9. CONTROL										15
10. EXTERNAL OIL FILLER										

Figure 4. The material flow intensity matrix for default process [17]

Following the completion of the calculation, the material flow intensity matrix is made. The values inside the matrix represent the transport intensity between the  $k$ -th and  $j$ -th element of the system. As each element of the system can be a source or a target point, the matrix is square. The material flow intensity matrix for default process is shown in Figure 4.

Based on the data given from the material flow intensity matrix, the mesh of the equilateral triangles is created. First two elements which are assigned in triangular mesh are the ones with the highest material flow between them; in this case they are assembling of the active part and control. Next elements assigned in the triangular mesh are defined by following the rules mentioned before in the text. Elements within the triangular mesh are labeled by numbers shown in the Figure 3. (e.g. Workstation 1 is 1, Control is 9 etc.). The triangular mesh of the default system is shown in Figure 5.

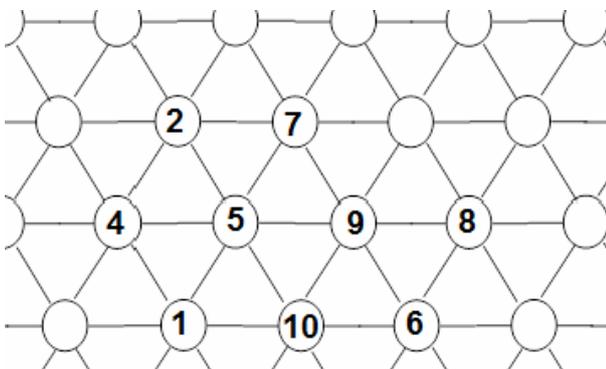


Figure 5. Mesh of equilateral triangles [17]

Based on the layout of the elements given in the triangular mesh, the minimum transport output for optimal layout is calculated:

$$f_c = \sum_{k=1}^m \sum_{j=1}^m b_{kj} \times s_{kj} = 638 \quad (3)$$

Transport output based on the current layout is also calculated and that value is 897 distance units/planning period, so it is evident that the current layout can be optimised. Based on the amount of the manufactured products, the planning period used in this case study is one year. In this case study only the optimization of location was used based on existing limitations. Taking into account some management limitations that some elements of the system must remain in the current positions (in this case those elements are the control station and both dryers) the new layout is proposed and shown in Figure 6. Also workstation 2 and workstation 3 are similar by their characteristics, so workstation 3 can be excluded from the system because considering the current amount of the products, it is not necessary to use both workstations. Eliminating workstations 3 from the system and the redistribution of the elements would enable extra space for storage of semi-finished and finished products (the area with hatch in Figure 6). Therefore, taking into account the listed limitations, the new minimum transport output is calculated and that value is 787 distance units/planning period.

The actual value of transport output is calculated by entering the actual distance between the elements (instead of a unit distance in the triangular method). The value of the transport output for the current state is 12554 m/planning period and the value of the transport output for the optimal layout (taking into account given limitations) is 9787 m/planning period. The results are shown in Table 1.

By redistributing of elements, the obtained savings would be 2767 m/planning period for the current amount of products. If the assumption is that the average transport speed is 5 m/min, it is calculated that saving time for transport is 9,2 hours/planning period, and also by eliminating the Workstation 2 and redistribution of the elements, a certain space is given (in this case 42 m<sup>2</sup>) which can be used for storage or something else.

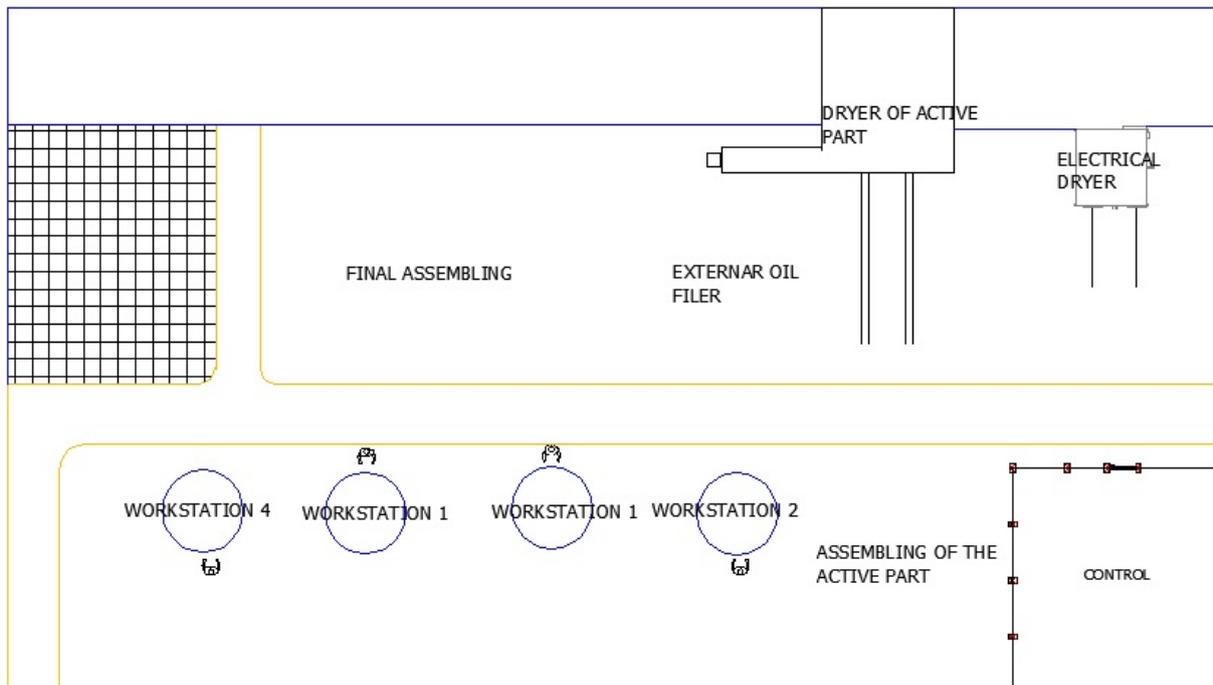


Figure 6. Proposed layout for the production hall

Table 1. Comparison between the current layout and the proposed one

	Distance units/planning period	m/planning period
Current layout	897	12554
Layout with implemented managment limitations	787	9787
Savings	12,26 %	22 %

## 5. CONCLUSION

This paper is a case study of the plant optimization in the production of special transformers. The goal of the optimization is to make cheaper and faster delivered products. Investing in new equipment is not always the best solution because it is costly and most companies buy new equipment and machines and install them where they have free space, not taking into account the material flow optimization. This can result in unnecessary transport cost rise. In many cases companies have reserves that can be exploited. One way to find these reserves is by using the material flow optimization with adequate dislocation of the working stands participating in the internal transport by Bloch-Schmigalla method. The analysis of the internal transport of the company has shown the potential of the optimization in respect of the material flow and the minimization of the cost involved in it. Although the analysis by Bloch-Schmigalla method has shown there could be improvements, they are minor considering the current amount of products assembled in the default production hall. But on the other side, it is important for the company to check the difference between the current layout and the optimal one because if the lead times are shortened and employees spent less time for transport they can do something else during that time. It is management decision if it is profitable to make

some changes in the system, taking into account calculated savings and possible costs. But if there will be a significant increase in the quantity of the product redistribution of the system elements into the optimal layout, it should be considered.

By redistributing elements of the system using Bloch-Schmigalla method, taking into account some management limitations that some elements of the system must remain in the current positions, the obtained savings would be 2767 m/planning period which is a reduction of 22 % compared with the current layout. Also, the utilization of the elements in the current layout is approximately 30 %, so there is a space for a significant increase in the quantity of the products. The optimization of the material flow must be followed by a standardization of the transport routes, manufacturing process, etc., in order to achieve further optimization of the production and shorter lead times.

With the obtained savings in transport times, the energy consumption of the material handling equipment is reduced, which leads to increased sustainability within the transport system.

As part of the future work it will be beneficial to use methods (e.g. Value Stream Mapping) to identify wastes in the whole production program. Also usage of simulation programs connected with Industry 4.0 would help to quickly (in real time) define wastes and other problems in the production and also in the warehouses, such as presented in papers [18, 19].

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## NOMENCLATURE

$b_{kj}$	amount of material flow amongst of elements of the system $k$ and $j$
$s_{kj}$	distance between locations of elements of the systems $k$ and $j$ , measured as the number of triangular line segments
$Q_{Si}$	batch size of component
$Q_{Poi}$	amount of components $i$ in one mean for disposal (a pallet, the most frequently)
$Q_{TSi}$	amount of means of disposal for component $i$ which are transported at once

## ОПТИМИЗАЦИЈА ПОСТАВКЕ ПОСТРОЈЕЊА ЗА ПРОИЗВОДЊУ СПЕЦИЈАЛНИХ ТРАНСФОРМАТОРА – СТУДИЈА СЛУЧАЈА

Д. Белић, З. Куница, Т. Опетук, Г. Дукић

Рад приказује студију случаја оптимизације поставке постројења за производњу специјалних трансформатора. Перманентна глобална криза је идеална прилика да компаније подигну ниво привредне способности, флексибилност и транспарентност операција и конкурентност на глобалном тржишту. Једна од могућности за побољшање наведених карактеристика је смањење унутрашњих трошкова искоришћавањем сопствених ресурса. Уз оптималан распоред радних места и опреме, путеви транспорта се скраћују, а тиме и радно време запослених, ослобађају се транспортна средства, скраћује се припремно-завршно време и број помоћних складишта се смањује или се затварају. Како запослени добијају више слободног времена могу га искористити ефикасније на оно што купац жели да купи. Осим тога, са скраћењем припремно-завршног времена проток материјала постаје бржи, скраћује се време чекања и смањује опортунитетни трошак капитала. Рад приказује које је кораке потребно предузети у циљу транзиције од постојећег до оптималног распореда радних места и опреме. За оптимизацију се користи Блох-Шмигалов метод троугаоне мреже.