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PARAMETRIC STRUCTURING OF PRODUCTION SYSTEMS TROUGHT ZONAL MODELS

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Abstract: Spatial optimization of machine production is an important element of project preparation of future production. The paper points out the fact that optimal dimensional models of future production is not just a matter of physical positions of manufacturing techniques, but it is also multicriterial function dependant for example on construction configuration of device and its peripheral elements, dimensional characteristics of production facilities, ergonomics, service availability, etc. CAD is a modifying variant of the production structure. In general is valid a principle that every unused space is costing us money. However, under sizing spatial patterns of production structures may cause us full range of partial issues for instance in logistics etc. An important implementation to tackle the problem is approaches based on mathematical modelling. The paper illustrates the mathematical modification of partial spatial analysis of possible 2D zonal solution as a necessary part in creating of the final model production. The suggested models of topological relations of constructed equipment of production models provide possibility of optimization of location problems. The models of topological relations in production systems are characterized of universality in application conditions and are suitable for designing automated production systems.

1 Introduction

1.1 Design of production systems

Engineering production has changed qualitative and organizationally. The current production systems integrate a large number of building elements (machines, robots, warehouses, transport system, control equipment, people) among which there are many complex linkages.

Designing is a creative process in space and time. The creation of production clusters defined its objective function. The reality of mutual compatibility of technical equipment, software, materials and people effectively guaranteeing the required functionality of future production unit addresses on the technical, economic and social base.

The work of the designer includes a series of complex intellectual activities associated with the process of collecting and processing information and application of the general patterns of production and technical procedures in order to achieve the creation of modification of the most effective forms of operating manufacturing market desired products. Project stages must be designed to achieve the highest efficiency solutions and take into account the latest scientific knowledge and knowledge practices. The designed system must operate reliably in real terms, to be technically and economically optimal throughout its use. Particular attention must be paid to issues of functional and spatial relationships that result in processing layout.

The output of the project activity is processing technology disposition production sites guaranteeing the required transformation of materials into the final product. Post illustrates the mathematical modifications partial spatial analysis of 2D zonal solutions occurring in the real structure of production clusters.

The project structure of the production system is a 2D/ 3D model (Fig.1) indicating a techno-organizational nature of the production process with spatial and temporal arrangement of production and aids. These are interconnected material and information flows and through them implement manufacturing operations on objects of production.

The current production systems integrate a large number of building elements (machines, robots, warehouses, transport system, control equipment, people) among which there are many complex linkages. The structure of the system model production system includes:

- objects that are undergoing the required transformation (material, parts, etc.),
- active agents (operators) that perform transformations (people, machines, tools, plant, equipment, physical environment),
- processes by which changes are made form, size, configuration, location etc.,
- inputs and outputs, which linked components with the environment, material flows, energy and information that form the overall architecture of

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the system and its associated elements into a whole,

- auxiliary components which are not directly involved in the outputs, but the ability to provide service system (maintenance, tools, etc.),
- space and time as necessary attributes of each system.

The general principle is that the unused space costs money. Spatial optimization of machine production is an important component of project preparation for future production. Optimal sized models of future production reports are not just a matter of physical deployment of production techniques, but also multicriterial function dependent eg. the structural configuration of the device and its peripheral components and dimensional characteristics of the object manufacturing, ergonomics, service and service availability etc..

Example of defining the functional areas of business in the grid of the space of the hall is in Fig. 2. The entire working area can be divided into grids, respectively into zones. The zone is bounded by space within the reference area, which involves a certain function or activity of entire production process. The number of zones and their geometric and qualitative characteristics determine the vastness of space to be placed production system and its structure.

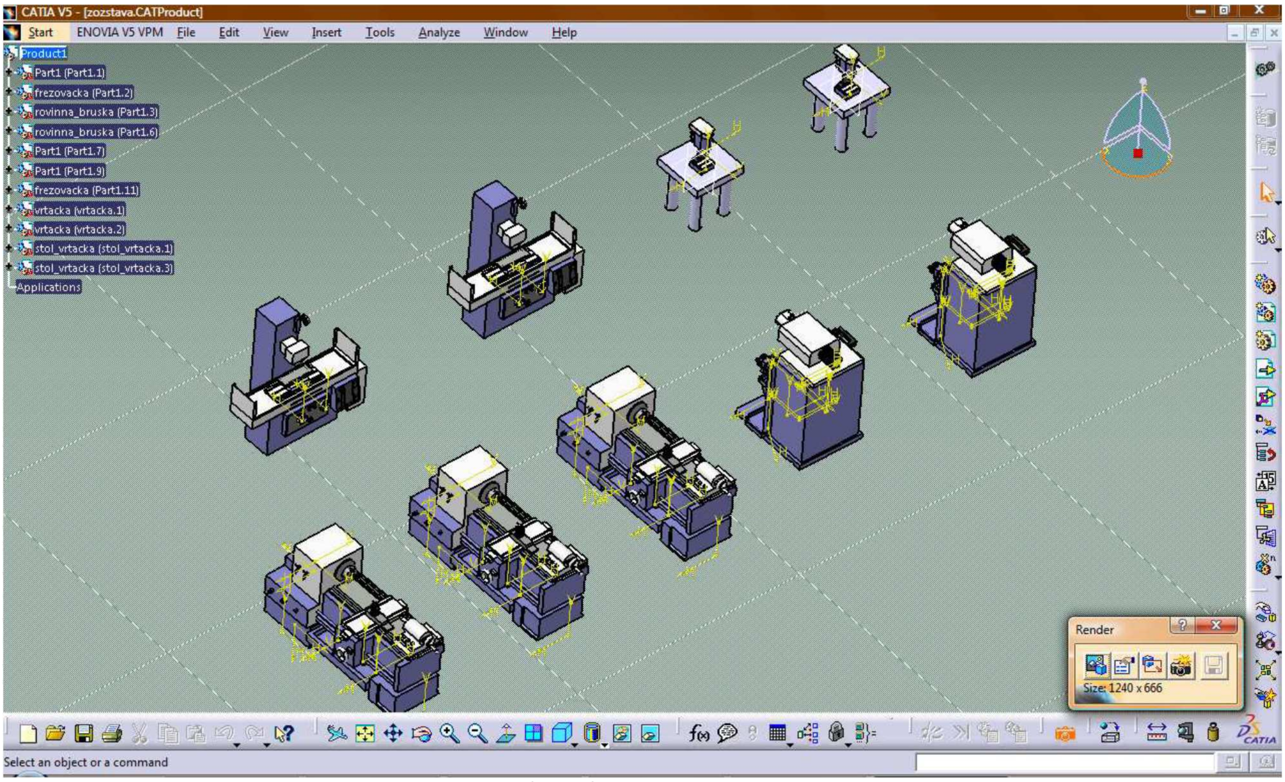


Figure 1 Example of modifying 3D CAD production structure

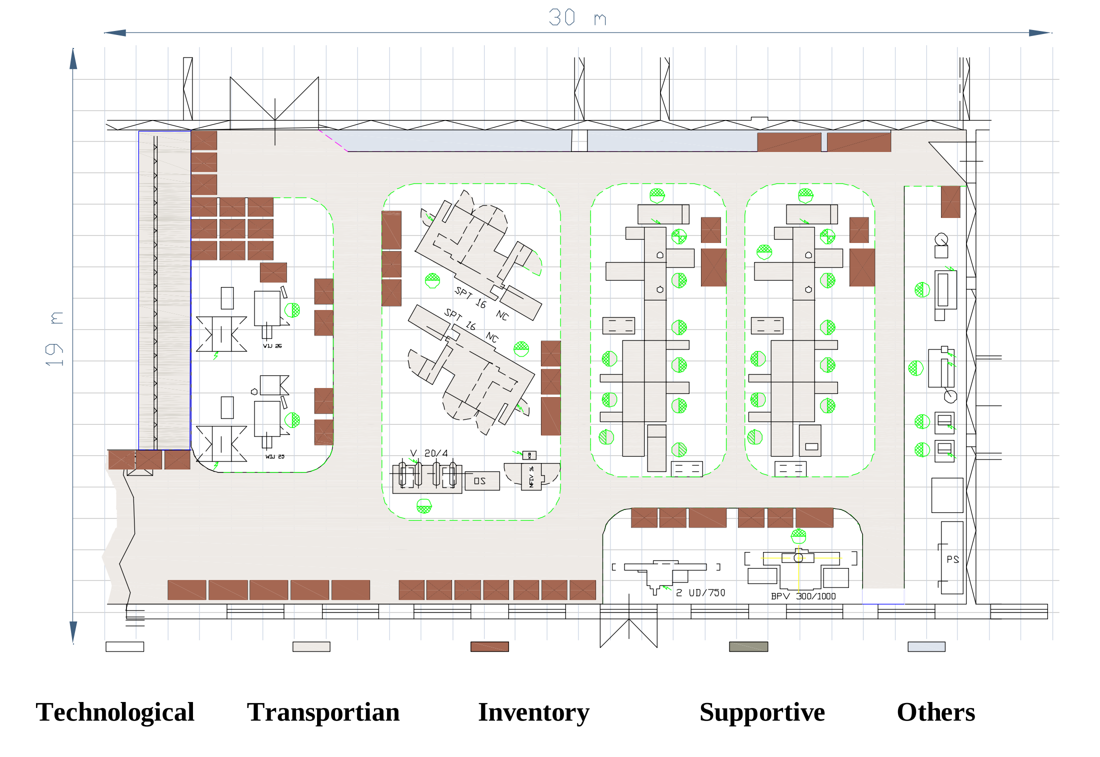


Figure 2 Defining the functional areas of activity in the grid of the space

Generally it can be described in its zone of its volume (in space) or in the examined section. By using this approach, the whole task is reduced to the description of the area bounded by the curves. After a suitable choice of the position coordinate system (depending on the particular case) is determined equation curves bounding zone and zone itself is then expressed as a set of points bounded by these curves. General form of the described area is as follows:

$$z = \{[x, y]: f(x_1), f(x_2), \ldots, f(x_i)\} \text{ where}$$

- x, y - coordinates of the points zone of the construction element in the chosen coordinate system,
- $f(x_i)$ - function expressing the shape of the curves bounding zone,
- i - number of curves bounding zone.

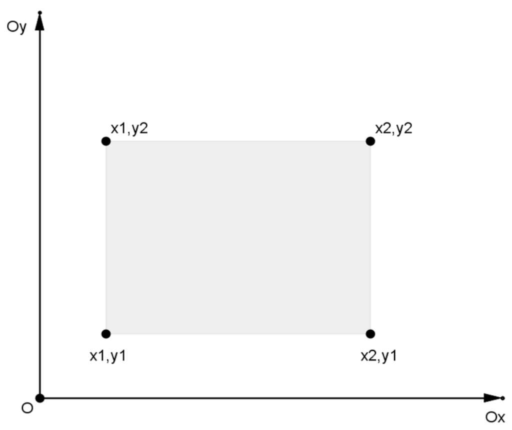
In describing the various zones and calculation of area proceed as follows:

1. Choose a coordinate system - the beginning of the coordinate system and orientation of the axes of the coordinate system (mostly right-handed Cartesian system).
2. The zone divides into elementary area. Elemental region is the set of points $[x, y]$ of the plane, for which the following applies: $a \le x \le b,\ f(x_i) \le y \le f(x_j)$
   - functions $f(x_i)$ and $f(x_j)$ are continuous on $\langle a, b \rangle$,
   - leave that to them (a, b) is $f(x_i) < f(x_j)$.
3. The shape of the elemental areas (according to the type of functions that bound elemental area) describes the area in question.
4. The size of the elemental surface area can be expressed by the double integral:
$$P = \iint_Z dxdy,$$
$$Z: a \le x \le b,\ f(x_i) \le y \le f(x_j).$$
5. The size of surface area is then the sum of the size of the areas of each elementary area.

The zones can be described by a Cartesian or polar coordinates, the choice depends on the shape of the elementary areas. If the limits in the elemental segment are lines or a polynomial function then it is more appropriate, to describe the area using a Cartesian coordinates and if limit elemental area is a circle or its part, then is more appropriate to describe area by using polar coordinates.

Examples of types of elementary area production zones work:

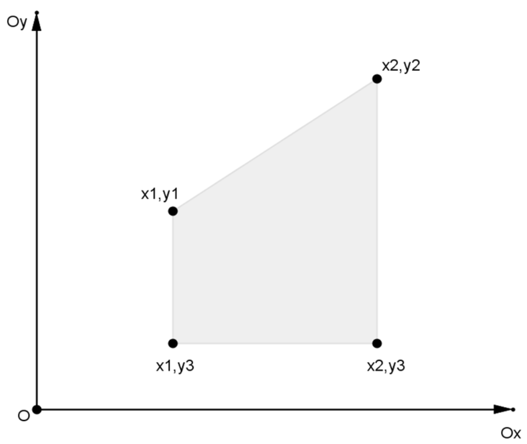
Elementary area „A"



- *Limits by lines paralel to „ o_x ".*
- *For elementary area holds:*
  $Z: x_1 \le x \le x_2$
  $y_1 \le y \le y_2$
- *Size of the elementary area:*

$$P = \iint_Z dx\,dy = \int_{x_1}^{x_2}\int_{y_1}^{y_2} dy\,dx = (x_2 - x_1).(y_2 - y_1)$$

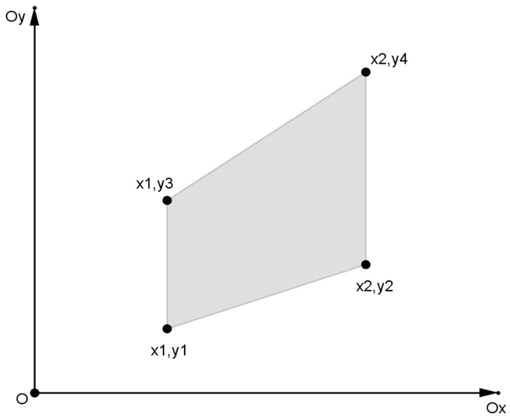
Elementary area „ B"



- *Limits by lines - paralel to „ o_x "*
  - independent to „ o_x ".
- *For elementary area is valid:*
  $Z: \; x_1 \le x \le x_2$
  $y_3 \le y \le f(x_j)$, *(resp.* $f(x_j) \le y \le y_3$*),*
  where: $f(x_j) = \dfrac{y_2 - y_1}{x_2 - x_1} x + \dfrac{x_2 y_1 - x_1 y_2}{x_2 - x_1}$
- *Size of the elementary area:*

$$P = \left|\iint_Z dx\,dy\right| = \left|\int_{x_1}^{x_2} \int_{y_3}^{\frac{y_2 - y_1}{x_2 - x_1}x + \frac{x_2 y_1 - x_1 y_2}{x_2 - x_1}} dy\,dx\right| = \left|\frac{(x_2 - x_1)(y_1 + y_2)}{2} - y_3(x_2 - x_1)\right|$$

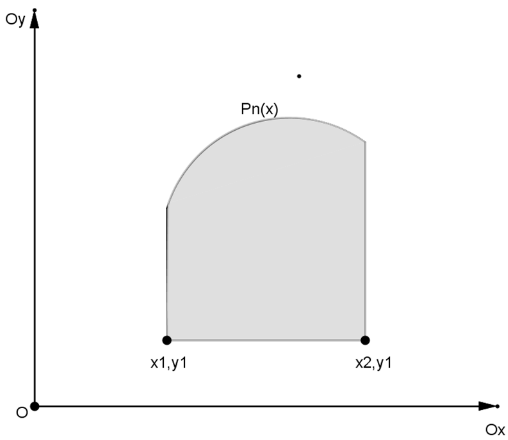
Elementary area „ C“



- *Limits by lines independent to „ o_x “*
- *For elementary area is valid:*
  Z: $x_1 \le x \le x_2$
  $f(x_i) \le y \le f(x_j)$, *where*
  $$f(x_i) = \frac{y_2 - y_1}{x_2 - x_1}x + \frac{x_2y_1 - x_1y_2}{x_2 - x_1},$$
  $$f(x_j) = \frac{y_4 - y_3}{x_2 - x_1}x + \frac{x_2y_3 - x_1y_4}{x_2 - x_1}.$$
- *Size of the elementary area:*

$$P = \iint_Z dx\,dy = \int_{x_1}^{x_2} \int_{\frac{y_2-y_1}{x_2-x_1}x+\frac{x_2y_1-x_1y_2}{x_2-x_1}}^{\frac{y_4-y_3}{x_2-x_1}x+\frac{x_2y_3-x_1y_4}{x_2-x_1}} dy\,dx = \frac{(x_2-x_1)(y_4+y_3-y_2-y_1)}{2}$$

Elementary area „ D“



- *Limits by lines paralel to„ o_x “ and polynomial n-th degree (eg.second degree polynomial)*
- *For elementary area is valid:*
  Z: $x_1 \le x \le x_2$
  $y_1 \le y \le a_2x^2 + a_1x + a_0$
- *Size of the elementary area:*

$$P = \iint_Z dx\,dy = \int_{x_1}^{x_2} \int_{y_1}^{a_2x^2+a_1x+a_0} dy\,dx = \frac{a_2}{3}\left(x_2^3 - x_1^3\right) + \frac{a_1}{3}\left(x_2^2 - x_1^2\right) + (a_0 - y_1).(x_2 - x_1)$$

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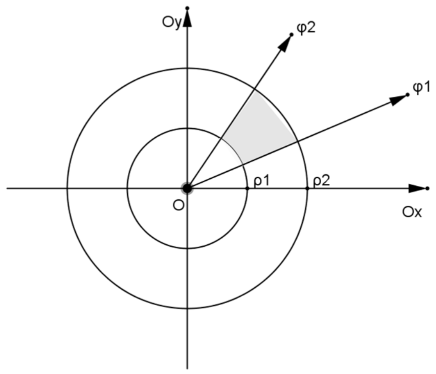
Elementary area „ E“



- *Limits by circle or part circle:*
- *When elements working in a different coordinate system then for rectangular, i is possible to use the transformation of polar coordinates:* $\rho, \varphi, (0 \le \rho \le \infty, 0 \le \varphi \le 2\pi)$.
- *For elementary area is valid:*
  Z: $\rho_1 \le \rho \le \rho_2$
  $\varphi_1 \le \varphi \le \varphi_2$
- *Size of the elementary area:*

$$P = \iint_Z \rho \, d\rho \, d\varphi = \int_{\varphi_1}^{\varphi_2} \int_{\rho_1}^{\rho_1} \rho \, d\rho \, d\varphi = \frac{(\rho_2{}^2 - \rho_1{}^2)(\varphi_2 - \varphi_1)}{2}$$

In addition to functional activities in the zone for a zone is characterized by the following basic parameters:

- *The shape of the zone.* It is possible to express analytically the system of equations. Equation surfaces bounding zone in the reference room, for example. the Cartesian workspace are:
  $x_{\min} \le x \le x_{\max}$, $y_{\min} \le y \le y_{\max}$,
  $z_{\min} \le z \le z_{\max}$, where
  $x_{\min}, y_{\min}, z_{\min}$ minimum size of the work area,
  $x_{\max}, y_{\max}, z_{\max}$ maximum size of the work area.
  This statement, however, is characterized as marginal areas workspace. More exactly, the working area (eg. in a robot) expressed train "*n*" inequalities $f_i(x, y, z)$, *i = 1,2 .... n*, since they are characterized by all points of desk area, not only points lying on the boundary surfaces.
- *Size of the area.* Depends on the size of each dimension of space, with elements of make depends on the extent of movement axes.
- *Accessibility zone.* It can be defined by the vector passing through the work zone point in the direction of the best access to the zone.
- *The position and orientation of the zone.* It is defined with respect to the coordinate system of space, respectively as a part of the construction element.

Workspace device is a set of all points in the reference area undergoing a functional activity. The limited space is referred as control zone facilities. Important features include: shape, size and volume of the work area accessible to the work area, the position and orientation of the work area with respect to the reference coordinate system.

Example of *real space* (RS) is in Fig. 3, this is actually a plan view of the built physical plant. This space is possible by suitable choice of the coordinate system, for example, divided into two elementary region of type A - C or elemental area of type A - B - B. The size of the actual surface area (footprint) is simply the sum of the sizes of areas of the elementary area.

Example *wasted space* (WS) is in Fig. 4. Utilizable workspace has a space that is covered by various auxiliary components such as structural components of construction equipment (protruding actuator, the end position of motion axes, etc.). This space is possible by suitable choice of the coordinate system (a combination of cartesian and polar coordinates) divided into elementary areas type A - D – E. Floor area wasted space is then given by the sum of the sizes of areas of the elementary area.

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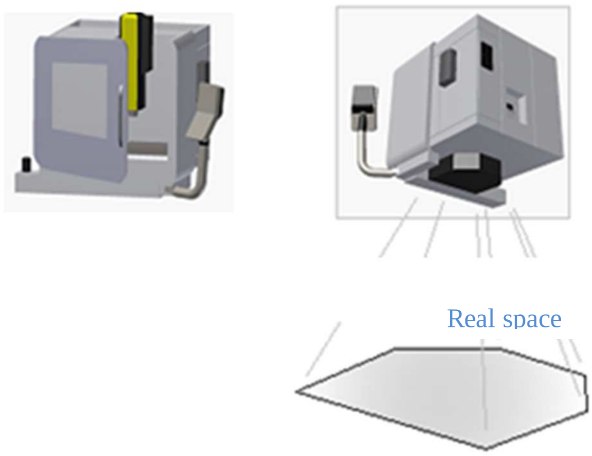

Figure 3 Real space

Figure 4 Wasted space

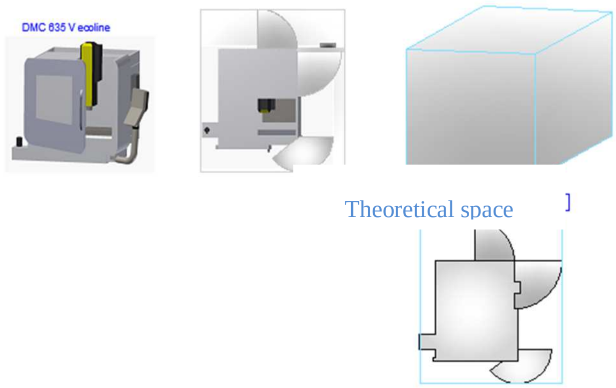

Figure 5 Theoretical space

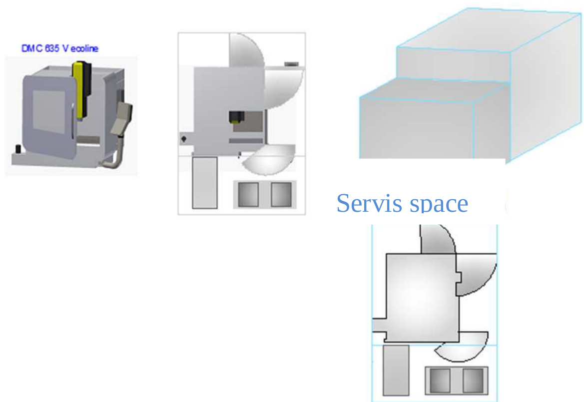

Figure 6 Servis space

Example *theoretical space* (TS) is in Fig. 5. Theoretical work space has a real space occupied by manufacturing facilities including service, control and energy footprint (space permitting open electrical cabinets, access to filtered air conditioning, tool magazines, etc.). This space is possible by suitable choice of the coordinate system (a combination of cartesian and polar coordinates) divided into elementary areas type A - D – E. Floor area of theoretical space is then the sum of the sizes of areas of the elementary area.

Example of the total *service space* (SS) is in Fig. 6. The confinement production structure realizes all the technological operations operate production equipment. In its definition should be based on size and weight characteristics of object registration. This area is removed by the appropriate choice of the coordinate system divided into elementary zones of types A, D and E. Floor area service area is then given by the sum of the size of areas of the elementary area.

When designing autonomous, modular modifications and their use, for example small business, resp. the business is in the production of space requirements for the equipment necessary to consider also the space for peripherals necessarily chosen to operate the production facility, for example compressor unit for compressed air and alike. Another determining factor can be inter-character and surgical manipulation (movement of the crane, etc.).

Comparing the size of the areas of different types of spaces it is valid:

$$P_{RS} < P_{WS} < P_{TS} < P_{SS} \text{ with } P_{SS} = \sum P_{RS} + P_{WS} + P_{TS} .$$

To determine the spatial characteristics of different types of spaces built production facility continues to be valid (Table 1).

Table 1 Mathematical description of the calculation of the spatial claims

Type of space	Elementary area	Size of the area
Real space	type A – C	$P = P_A + P_C = \iint_{Z_A} dx\,dy + \iint_{Z_C} dx\,dy$
Theoretical space	type A – D – E	$P = P_{A1} + P_{A2} + P_{A3} + P_D + P_{E1} + P_{E2} + P_{E3} + P_{E4} =$ $P = \iint_{Z_{A1}} dx\,dy + \iint_{Z_{A2}} dx\,dy + \iint_{Z_{A3}} dx\,dy + \iint_{Z_D} dx\,dy +$ $+ \iint_{Z_{E1}} \rho\,d\rho\,d\varphi + \iint_{Z_{E2}} \rho\,d\rho\,d\varphi + \iint_{Z_{E3}} \rho\,d\rho\,d\varphi + \iint_{Z_{E4}} \rho\,d\rho\,d\varphi$
Wasted space	type A – D – E	$P = P_{A1} + P_{A2} + P_{A3} + P_{A4} + P_{A5} + P_D + P_{E1} + P_{E2} =$ $P = \iint_{Z_{A1}} dx\,dy + \iint_{Z_{A2}} dx\,dy + \iint_{Z_{A3}} dx\,dy + + \iint_{Z_{A4}} dx\,dy + \iint_{Z_{A5}} dx\,dy +$ $+ \iint_{Z_D} dx\,dy + + \iint_{Z_{E1}} \rho\,d\rho\,d\varphi + \iint_{Z_{E2}} \rho\,d\rho\,d\varphi$
Servis space	type A – B – D - E	$P = P_{A1} + P_{A2} + P_{A3} + P_{A4} + P_B + P_D + P_{E1} + P_{E2} =$ $P = \iint_{Z_{A1}} dx\,dy + \iint_{Z_{A2}} dx\,dy + \iint_{Z_{A3}} dx\,dy + + \iint_{Z_{A4}} dx\,dy + \iint_{Z_B} dx\,dy +$ $+ \iint_{Z_D} dx\,dy + + \iint_{Z_{E1}} \rho\,d\rho\,d\varphi + \iint_{Z_{E2}} \rho\,d\rho\,d\varphi$

Conclusions

An analysis of current approaches to the description of the premises and areas show a relatively high degree of fragmentation. Most descriptions of a formal nature and its design is virtually little usable. For practical use are needed more exact descriptions, using mathematical and other principles applicable especially in automation design.

The proposed models workspaces manufacturing facilities provide the possibility of such deployment optimization problems. Models decomposition into elementary space area is characterized by considerable versatility in terms of application conditions, because they are suitable for design automation, as well as traditional manufacturing facilities.

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