PRODUCTION PROCESS LAYOUT OPTIMIZATION WHEN COMBINING TWO EXISTENT SYSTEMS

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Abstract: *In modern manufacturing environments, integrating existing production systems poses significant challenges related to layout design, operational efficiency, and resource allocation. This study addresses the optimization of production process layouts in scenarios where two independent systems must be physically and functionally connected. The primary objective is to minimize material handling costs, streamline workflow, and reduce potential disruptions during integration. We had two manufacturing plants (the assembly and the machining part) to be combined into a comprehensive system. At the same time, the placement of machines and logistics routes in the production process were optimized. We want to combine and optimize all business functions and take the advantage of the synergies in both systems, as well as the professional technological potential. The findings contribute practical insights for industrial engineers and decision-makers tasked with upgrading or merging legacy systems within constrained physical spaces.*

Key words: *Production system, Optimization model, Layout, Optimization methods, Synergies*

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1. Introduction

Regardless of which transformations are used in the factory, there are four important measures of output (Eilon, 1962): quality, quantity, time and price. This depends on various factors, such as the type and complexity of the product manufactured, the quality of the raw materials, the complexity of the manufacturing process and the arrangement of the workstations that make up the production process. Some of these parameters are determined by the product and are therefore unchangeable; others are variable and can therefore be improved. The challenge of determining the best arrangement of workstations is one of the elements that have a major impact on system performance (De Carlo et al., 2013). It is known as the "facility layout problem" (Kusiak & Heragu, 1987), namely the problem of arranging everything needed for the production process.

Facility layout design determines how the operating equipment, storage areas, materials handling equipment and all other support services should be arranged, located and distributed in a production facility to minimise overall production time, maximise operational and layout flexibility, maximise work-in-process turnover, achieve safer working conditions and maximise production output in accordance with production schedules (Tompkins et al., 2003).

Traditionally, four types of layout are considered appropriate for a manufacturing facility – Functional (Process, Job shop), Flowline (Product, Flow shop), Cellular (Group) and Fixed location layout (Stationary layout). The ideal manufacturing layout depends on the production volume and product variety (Fig. 1).

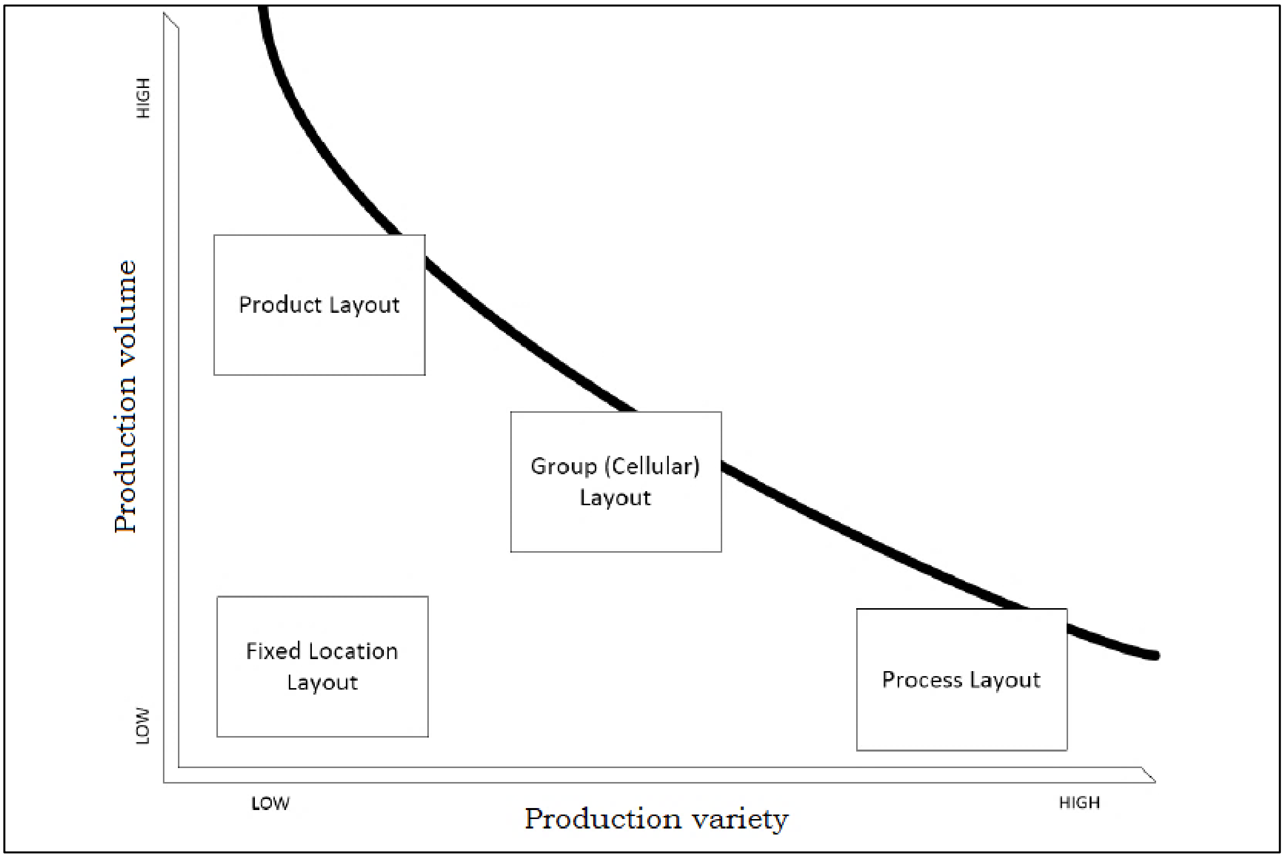

Fig. 1. Manufacturing layouts and volume / mix (Baudin & Netland, 2023).

The problem of designing the layout of workplaces is generally the placement of *n* workplaces at *n* or more possible locations, whereby the target function must be fulfilled or the optimum solution found. This theoretically results in *n*! layout variants, but due to the large size it is not possible to calculate them all (Choi et al., 2024).

The facility layout can be created with many different approaches (Vujica et al., 2021). It has similar characteristics and objectives to the ideas of lean production: it is aimed at reducing all types of waste, such as transport time, space and unnecessary workstations. The benefits resulting from effective layout planning are numerous. In fact, transport is the key factor in the facility layout planning problem (Buchmeister, 2024). In addition to the direct goal of minimising material handling costs, effective facility layout planning also has indirect benefits: for example, it can help to reduce lead times (Askin & Standridge, 1993), or it can simply facilitate the control of information and material flow (Fu & Kaku, 1997), as well as improve communication between different units, efficiency, flexibility and space requirements (Zuniga et al., 2020).

Greater efficiency and effectiveness in solving problems can be achieved through greater systematics. However, an increase in systematicity can be achieved by using a general methodology for problem solving and system building. Such a methodology is therefore needed by all those individuals and organizations who want to get from the existing to a new – desired state. Changing the existing reality is becoming more and more demanding, often even more demanding than our knowledge and abilities. That is why it often happens that what we have newly built is better from one point of view and worse from another, better for one and worse for the other, better for the organization and worse for the environment, better for today and worse for tomorrow. When taking big and rapid steps into the new – the unknown, we cannot completely avoid this, because our ability to understand the state and processes is limited. This realization was followed by efforts to refine approaches or methodologies to change reality. The remaining of this chapter is describing the following problem: we have an assembly workshop and machining workshop (with four machining groups) for valve production. The cost of duplicating certain business functions, as well as the logistics of production, is too high. Therefore, we will undertake the optimization of production, and its functions related to production and try to combine functions in the process itself. In this way, we want to increase productivity, shorten the operating times of individual functions, in short, optimize the entire production of the work process.

2. Optimization in factory planning

Optimization in factory planning is a critical process that involves strategically organizing resources, workflows, and operations to maximize efficiency, reduce costs, and enhance productivity. By applying mathematical models, data analysis, and simulation techniques, factory planners can make informed decisions about layout design, production scheduling, inventory management, and workforce allocation. Effective optimization ensures that manufacturing systems operate smoothly, adapt to changing demands, and maintain a competitive edge in today’s fast-paced industrial environment.

Optimization is the field of activity for the methodical development of optimal solutions that are possible by incorporating variable influencing factors and optimization models.

2.1 Optimization areas in factory planning

Due to the task of factory planning to develop effective factory systems, factories and entire factories and to plan them ready for implementation, optimization is a diverse field of activity that should not be considered separately but rather integrated into the project planning methodology, steps and stages and should be carried out alongside the project planning. This is related to the designer's knowledge in optimization in general and in particular, in dealing with the field of optimization with a specific task, in modelling optimization (optimization model) and in optimization methods, see Fig. 2.

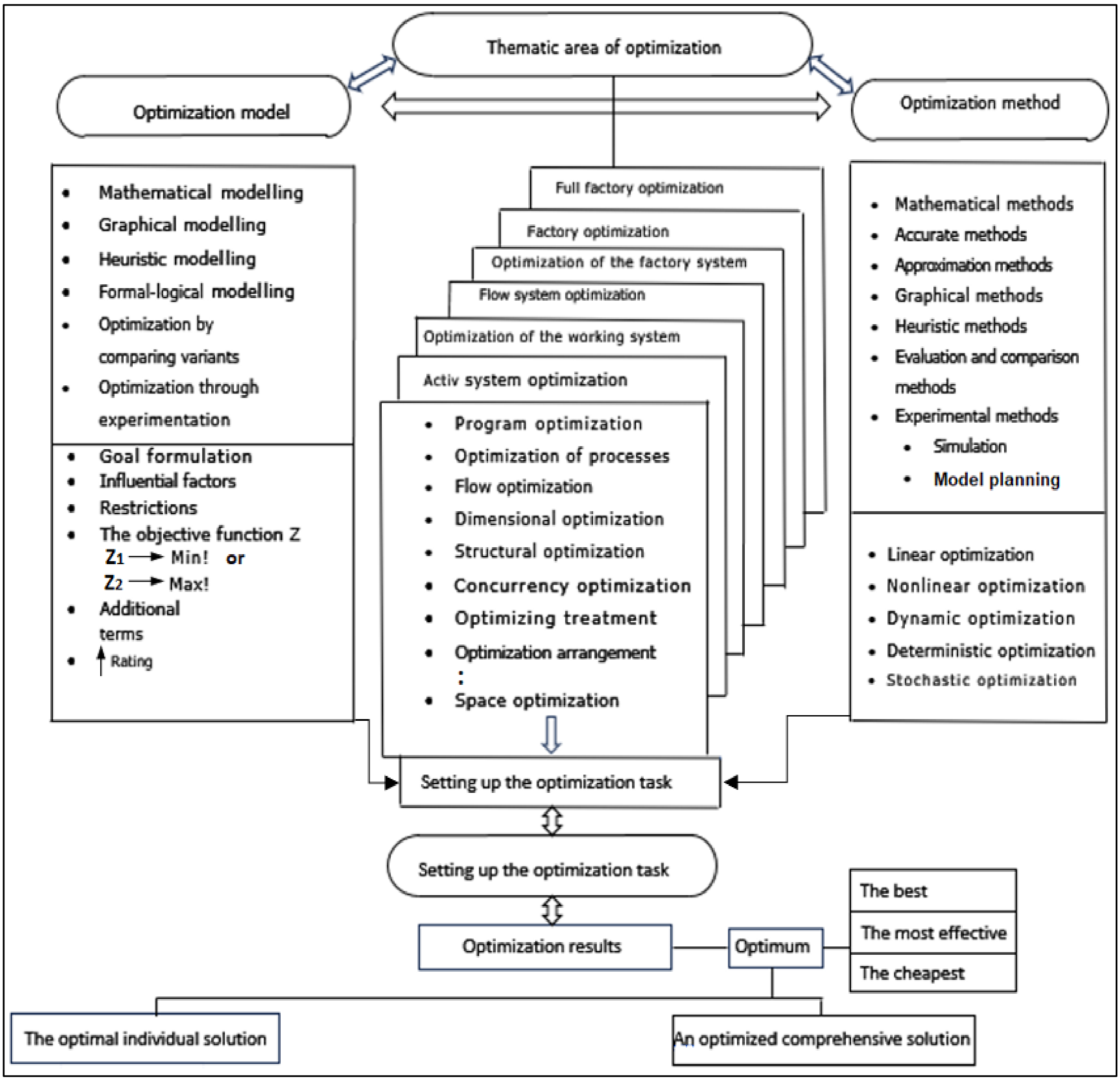

Fig. 2. Selected optimization areas in factory planning.

Optimum is the result of optimization achieved under certain conditions and has validity only with respect to these conditions. A change in conditions leads to a change in the optimal solution. Therefore, it is always relative and serves as a guideline in the "right direction", especially due to the impossibility of including all the conditions that affect the optimal solution.

2.2 Optimization principles for factory planning

The basic task of factory planning, starting from the formulated task (production program), is to develop optimal factory systems for all system hierarchical levels (from the working system to the entire factory system) with creative plans and prepare them for implementation. For this system hierarchy consistency, project planning methods are largely available and ready for use, without a consistent mathematization of the optimization being possible.

2.3 Optimizing the assignment of an object to the site

A very common task in planning is to determine the optimal connections between workplaces, buildings and sites (Fig. 3). Examples include:

- Arrangement of machines in the workshop system.
- Arrangement of workshop systems in the factory premises or throughout the factory.
- Distribution of factory premises throughout the factory (development of the factory site).
- Determining the location of the factory.
- Warehouse organization (arrangement of storage areas) or
- Warehouse layout.

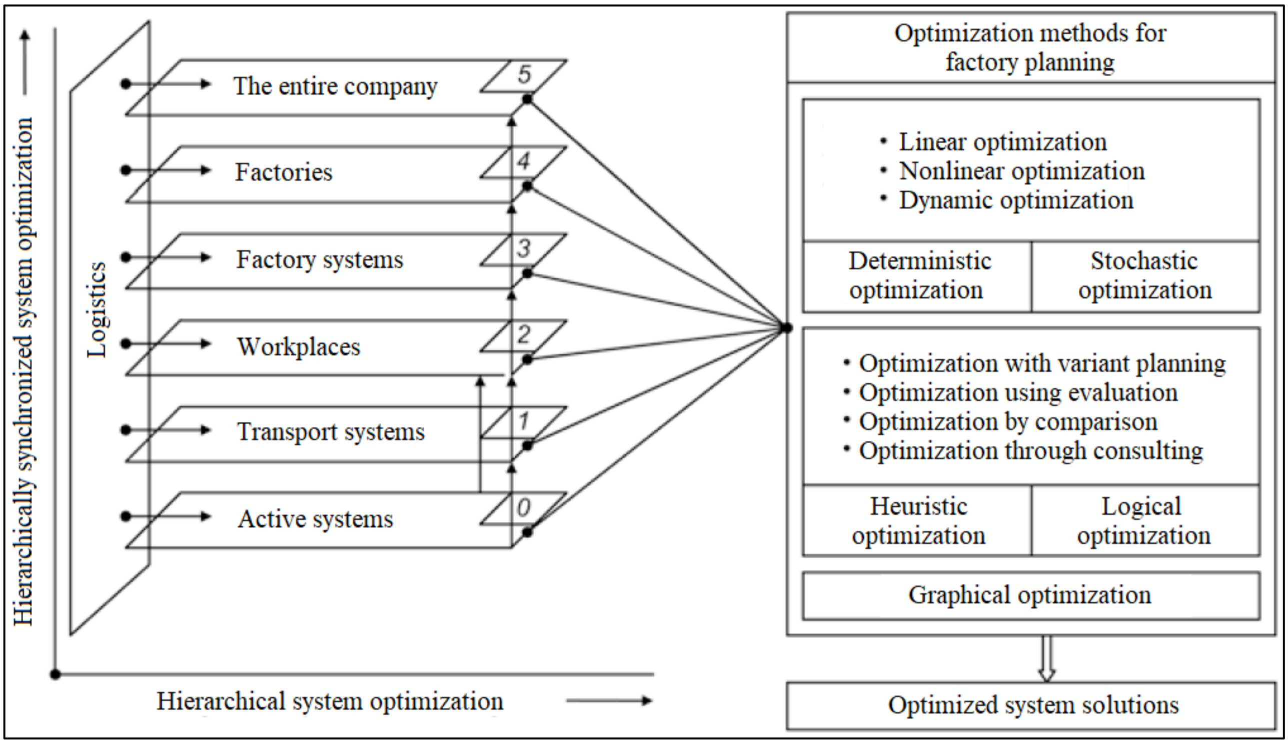

Fig. 3. Hierarchical system optimization in factory planning.

Linear programming methods are mainly used to solve these allocation problems.

A simple and effective way to solve the assignment problem is the Hungarian method (Kuhn, 1955). This method was named by Kuhn to honour Hungarian mathematicians Kőnig and Egerváry.

While the Hungarian method is limited to point-based system processes, different hierarchical references may apply (Fig. 4).

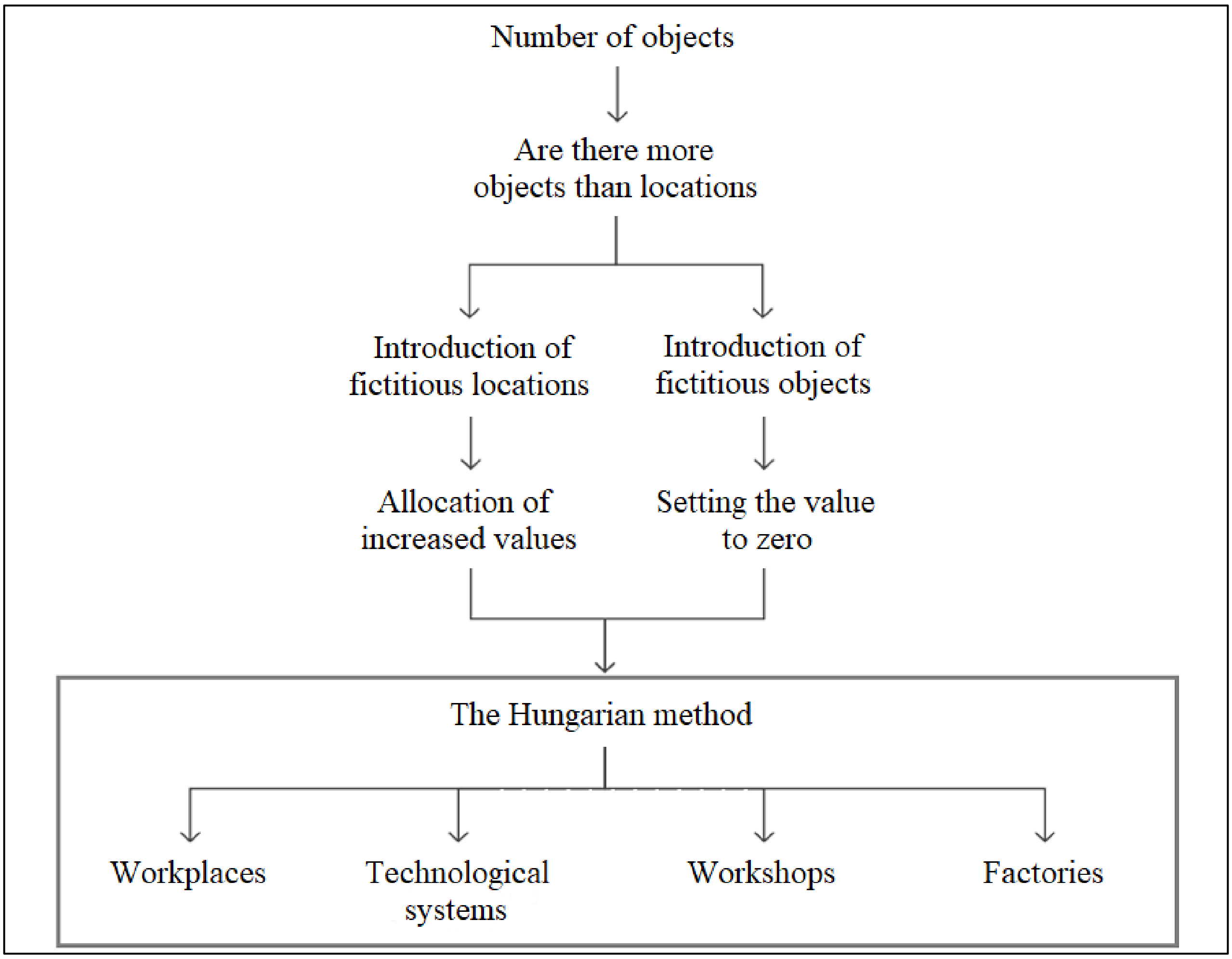

Fig. 4. The Hungarian method and hierarchical references.

The optimization of the allocation of workshops to sites is related to the verification of the size of the areas in the case of unequal requirements for the area of workshops and unequal bids for locations. Facilities that cannot be placed in certain locations (limitations) due to area size constraints receive elevated distance values for those limiting locations. This excludes the assignment. For this, we will use familiar methods with the peculiarities of the production process, as well as the characteristics of two separate sites. By analysing layout configurations and applying optimization techniques this research provides a structured approach for achieving efficient system interoperability.

Depending on the process, the following should be taken into account:

1) Point-like processes or processes without interconnection relations, other than input-output relations, can be precisely optimized using the Hungarian method (Dantzig, 1966).

2) Linear processes do not require object arrangement optimization because the object assignment is determined by the connection relations.
3) Unidirectional network processes can be considered as linear processes, if the direction of flow is clearly defined.
4) For linear and unidirectional coupled processes, the main goal is to determine the transport-optimal input and output allocations, rather than the process itself in the system.
5) Processes with multiple directional links can only be optimized approximately, for example by a modified triangular procedure and by a modified allocation procedure.

3. Optimizing object layout with the Hungarian method

The method has been developed more than 70 years ago by Hungarian mathematicians. It is explained by the following example used for the layout optimization of the connected system.

3.1 Application requirements

Below is the list of basic requirements for the application of the method:

- Objects with point-like processes (individual production, warehouse, systems in the factory).
- Known objects and possible locations.
- Objective function (effort minimization).
- Effort values of the objects (O) (for factory planning especially transport frequency values).
- Effort values of the locations (L).
- Effort matrix as zero matrix and calculation basis.

3.2 Steps of the method with factory example

The method calculation sequence is clear, but it is often described differently. The planning-oriented description with our example is provided here.

Step 0: Starting point as a zero matrix (4 objects O or object groups and 4 locations L). All values are in transport meters per day.

0-matrix	L1	L2	L3	L4
O1	1045	935	1130	810
O2	1160	1180	1340	1030
O3	589	539	692	550
O4	853	703	918	594

Step 1: Find the minimal values in each row of the 0-matrix and write them in the inserted column on the right.

Step 2: Subtract the minimal values in all cells of each row and form the Matrix 1 with these results.

0-matrix	L1	L2	L3	L4	Min.
O1	1045	935	1130	810	810
O2	1160	1180	1340	1030	1030
O3	589	539	692	550	539
O4	853	703	918	594	594

Matrix 1	L1	L2	L3	L4
O1	235	125	320	0
O2	130	150	310	0
O3	50	0	153	11
O4	259	109	324	0

Step 3: Find the minimal values in each column of the matrix 1 and write them in the inserted row at the bottom.

Step 4: Subtract the minimal values in all cells of each column and form the Matrix 2 with these results.

Matrix 1	L1	L2	L3	L4
O1	235	125	320	0
O2	130	150	310	0
O3	50	0	153	11
O4	259	109	324	0
Min.	50	0	153	0

Matrix 2	L1	L2	L3	L4
O1	185	125	167	0
O2	80	150	157	0
O3	0	0	0	11
O4	209	109	171	0

Step 5: Check whether a unique assignment has been achieved that represents an optimal solution. Solution condition: the optimal assignment solution is found when only one zero (△) occurs for a row and column that is not occupied by other columns or rows for the optimal solution. Cover lines D are used for the determination. The optimal assignment is at $m = D = \Sigma△$.

Matrix 3	L1	L2	L3	L4
O1	185	125	167	△0
O2	(80)	150	157	⊗
O3	△0	⊗	⊗	[11]
O4	209	109	171	⊗

$m = 4$, $D_{min} = 3$ element k element K cover line D

The following rules apply:

Rule 1: Cover lines D shall be placed above the zero elements of the matrix horizontally or vertically, or in both directions.

Rule 2: The minimum number of cover lines D is determined by surrounding the maximum number of zero elements with a cover line.

Rule 3: The optimal allocation is achieved when the minimum number of cover lines D matches the number of elements of the matrix *m*.

Rule 4: When the optimal solution is reached by $D_{min} = m$, the calculation is completed. This is followed by the determination of the allocation under Rule 5.

Rule 5: The assignment shall be determined for the marking of null elements (△) that apply only to one row and column. All other zero elements covered by a cover line are deleted (⊗). These null elements are no longer available for the assignment.

Rule 6: If the optimal solution has not yet been reached ($D < m$), continue the calculations in step 6.

Step 6: Find and mark (O) the smallest element k in matrix 3 that has not been covered by a cover line. Subtract the value of the element k from all cells of matrix 3 that are not covered by the cover line and enter the results in matrix 4. Add the values of element k to the crossing elements K and transfer the results to matrix 4. Use step 5 to check optimization. Continue to use step 6 and step 5 until the final solution is reached. The number of matrix is increased by one for each subsequent use.

Matrix 4	L1	L2	L3	L4
O1	105	45	87	0
O2	0	70	77	0
O3	0	0	0	91
O4	129	29	91	0

$m = 4$, $D_{min} = 3$

Matrix 5	L1	L2	L3	L4
O1	105	16	58	0
O2	0	41	48	⊗
O3	29	⊗	0	120
O4	129	0	62	⊗

$m = 4$, $D_{min} = 4$ => optimal solution

3.3 Results

Optimal solution is calculated with the values from the zero matrix.

L1	L2	L3	L4	Location
O2	O4	O3	O1	Object
1160	703	692	810	(Σ) 3365

The optimal allocation requires 3,365 transport meters per day. Since a more favourable assignment with initial values (matrix 0) is not possible, it is possible to proceed with the design. This usually means carrying out the layout planning process with an inspection and possible corrections to the areas.

Fine-tuning can bring about minor changes in transport routes that may require the reassignment of facilities to sites. Recalculation is often necessary at the stage of rough design execution. In practical use, we can combine and treat matrices 0 and 1 and matrices 2 and 3 for a given user routine.

With rare exceptions, as many practical applications show, the number of steps to solve the layout problem approximately matches the number of columns (m) or rows (m). This also allows manual use for larger matrices ($m >> 30$). If additional calculation steps are required, this is often due to incorrect application of rule 2 in step 5.

If there are more objects to be allocated than available locations, a correspondingly high number of fictitious locations shall be taken into account. These are assigned elevated values in the matrix. If the number of objects is less than the number of locations, fictitious objects are introduced. The matrix values for these fictitious objects are set to 0.

The result of our optimization for the connected system with all departments is given in Fig. 5.

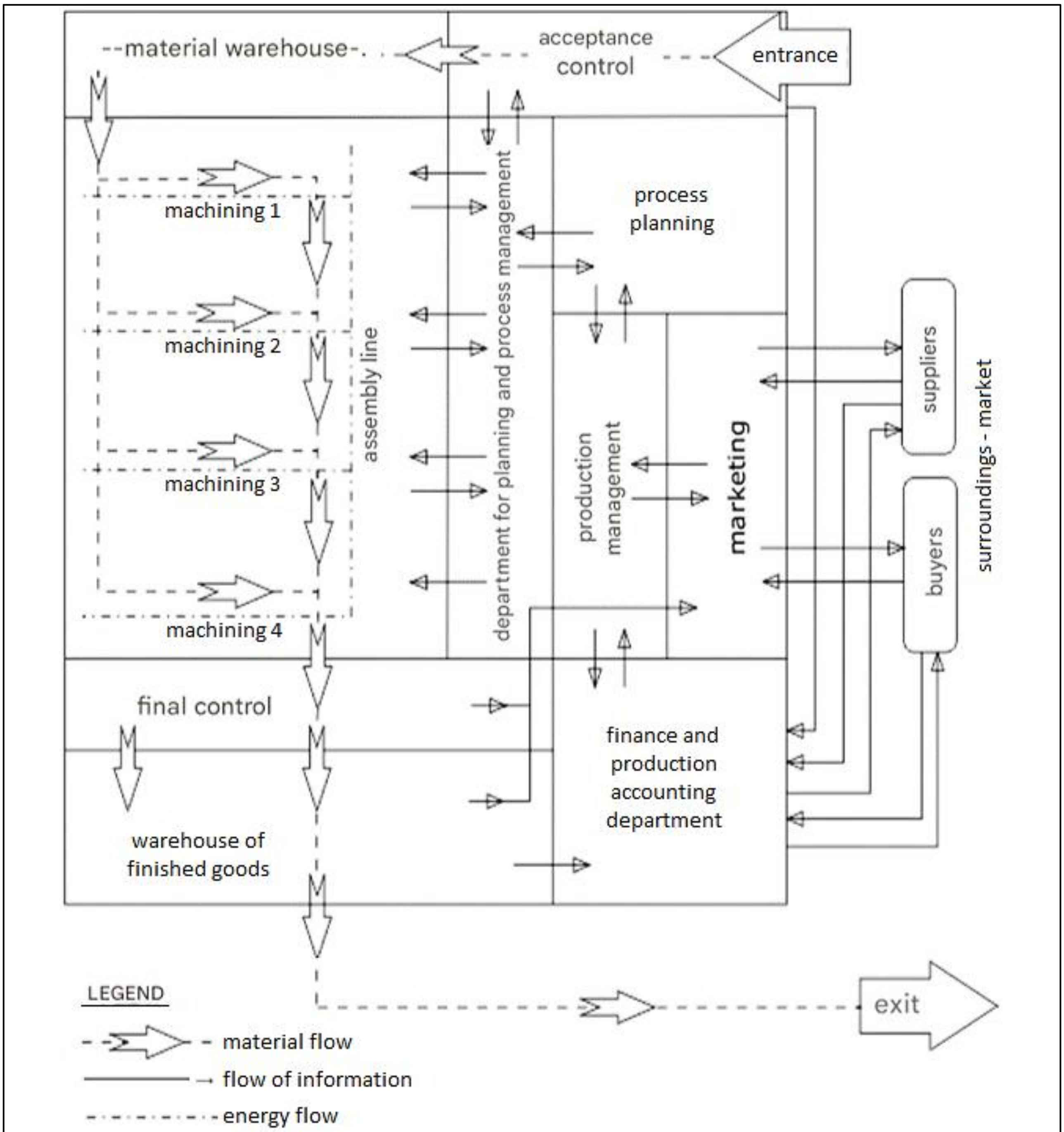

Fig. 5. A new connected system with flow of material, information and energy.

4. Conclusion

We had two systems, assembly and machining workshops. Due to the dislocation of the systems, the systems' own management functions, different information systems and poor coordination, both production systems were unstable and sensitive to market developments, both on the sales, production, purchasing and information sides. Also, the disconnection of the systems was reflected in the insufficient flexibility of the technological process, the product development component, the quality and generally measurable economic effects related to the above-mentioned shortcomings. As a result, in practice, it turned out that one of the systems – the assembly system – went bankrupt and that the entrance to the processing system was therefore also threatened. The guiding thought of building a connected system was how to transform existing systems that we were not satisfied with into the desired system by using as many components of existing systems as possible. Creativity, then, was not about finding new components, but about finding new connections between them. We only rebuilt (or bought) those components that we didn't have in the existing systems, and we couldn't possibly miss them in the new system. The more new components in the system mean greater the risk of the project's success, and the greater the difficulties in coordinating the individual components of the system.

With the project of renting a machining system in bankruptcy by the cultivation system, the entry into the processing system was temporarily ensured and thus the exit from it in the form of the sale of products. In this way, the primary market share of the production system was preserved, and secondarily the machining system. With the subsequent connection of the two systems, a reorganized streamlined system with a unified control system occurred, simultaneously with increased inertial effects. Such a system has provided increased economic indicators in the form of increasing market share, sales and profits.

The connected system has also become more flexible and stable. More flexible in terms of conquering and developing new products, more elastic response to market requirements – customers, and delivery times – "just in time". It has become more stable in terms of more permanent provision of production, and consequently jobs, and thus also contributed to the development of the entire local area. Increased economic indicators also contributed to the parallel development of other economic activities in the local area. In this way, we have developed a new business and technical production system in parallel, as well as a parallel social one. Synergistic effects contributed to the efficiency of the system and reinforced the correctness of the decision on the newly installed system. The systems theory, layout optimization and stochastic prediction methods used were the tools that helped to facilitate the formation of a newly connected system.

In this chapter, we have only shown part of the layout optimization in more detail. The integration of two existing production systems requires more than a simple physical connection – it demands a strategically optimized layout that ensures continuity, efficiency, and adaptability. Through the application of layout optimization method, this study demonstrates how careful planning can significantly reduce operational inefficiencies, material handling times, and spatial constraints.

The proposed approach not only supports smoother transitions between systems but also offers a replicable framework for future integration efforts. Ultimately, this work underscores the importance of layout design as a critical factor in the successful unification of established production environments.

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