Optimization of the equipment positioning in manufacture of Tissue Paper

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Optimization is a procedure to find the best solution of a set of possible solutions for a problem. Many processes can be benefited from an optimized allocation of resources. These resources, that can include capital, equipment, tasks and time, must carefully be placed in the correct amounts, the correct times, and the correct sequence for the best result to be obtained. These are complex problems, many times of difficult solution, and that may involve significant reductions of costs, improvements of times of processes, or one better allocation of resources in activities. Mathematical models can be used to get the layout of a more economical process, subject to restrictions that make possible the operation, maintenance and safety. Therefore, the models aim to minimize the total cost, while they satisfy the restrictions of free space of the components. One application is in the production of tissue papers, which encloses the toilet papers, that account for 80% of the production, the towels (16%) and napkins (4%), used by large consumers, such as fast-food nets, hospitals, offices, industries, etc. Brazil contributes with 2.8% of the world-wide production, since 1990. Moreover, the country is 9th producing world-wide of toilet paper. Based on this, this work had as objective a study of the optimization of the equipment localization in the manufacture of tissue paper. We use for this the previous work developed by (DRUMMOND, 2003) where the objective was the implementation in GAMS of the model developed by (GUIRARDELLO, 1993) in the manufacture of tissue paper. The model was formulated as a mixed integer linear programming (MILP). For the resolution of the model it was used a Sun Enterprise E250 400 MHz, where the software GAMS/CPLEX 7.5 was installed. The original problem was considered with 15 main components, and then reduced to 10 by a grouping of components. This grouping was not arbitrary, but it was based on the requirements that components needs to be necessarily together to other components, as for example, bombs to the side of tanks. The problem was them solved to optimality (zero gap) with the branch-and-bound procedure, resulting in an optimal layout in an acceptable time.

1. Introduction

The layout development of a chemical plant is part of a more general process, i.e., the global design of the plant. This one comprises six steps:

1. Problem definition and conception. In which basic aspects and hypothesis should be well known, as well as plant capacity and time distribution. In this stage the objectives of the plant, its economical viability and flexibility to eventual changes are investigated.
2. Development of the process fluxograms. It allows for the process familiarization, reduces the process complexibility and identifies the missing information.

3. Equipment design. At least a preliminary design is required to produce information for economical assessment. Beyond that, equipment manufactures and vendors need more detailed information, such as material to be used and tank wall thickness.
4. Economical analysis. "How much money will be earned for the investment made?" The answer requires determination of raw materials, equipment, labor and processing costs, as well as knowledge about inflation rates, taxes, etc., which affects the industry profitability as a whole.
5. Optimization. A balance between engineering and economics. The optimum is searched considering all factors involved. The factory components placement is regarded here, which is the topic of this work.
6. Report publication. The previous work is presented in a clear and organized way, to guarantee absence of doubts.

The enterprise is the major ground for layout definition, which targets the arrangement and integration of productive elements. The issue regards the placement of office departments and plant machines. The problem may be very complex, due to the variety of geometrical and combinatory aspects involved. Furthermore, industrial layout comprises quantitative and qualitative factor, which when associated, may be difficult to analyze and solve. Usually, it is always better to simplify the general problem, splitting it into smaller and separated problems. This would reduce the size and complexity of the problem, allowing a comprehensive study of alternatives. Layout definition (physical arrangement) searches for the optimal combination of industrial facilities involved in manufacturing, regarding an available space. Layout is the way in which people, machines and equipment are arranged within a factory. The layout definition challenge is to obtain the most effective placement of the various production areas in the plant. It is to reach the best use of the available space which would promote the most effective processing, by reducing distance and time. Physical arrangement planning may be useful to any company, big or small. With a good physical arrangement, a company may obtain surprising results considering cost reduction and productivity enhancement. For a new plant, this planning is mandatory. Regarding existing plants, change in current arrangements may result whenever there is need for changes in process, new products manufacturing, cost reduction and expansion. The ideal layout achievement may be hampered by space limitations, available time and absence of qualified personnel. Nevertheless, the ideal layout sets a guideline for any modification. An adapted layout is the way to go then.

The objective of this work was to optimize the layout of a tissue manufacturing plan, using mathematical modeling (Guirardello, 1993, 2005), solved by GAMS/CPLEX version 7.5. The main interest in this kind of problem is the size of the equipment involved in a paper plant, some of them quite large, so that the definition of an optimal layout is very important

2. Mathematical Modeling

A mathematical model for a specific situation is a set of mathematical equations, inequations and logical conditions, which represent virtually the real system.

The optimization procedure searches for values that maximize or minimize an objective function, satisfying restrictions relating the variables. A model may have continuous variables, integer variables or a set composed of a mixture of them. The parameters are determined by one or multiple values, and each value defines a new model.

For a process plant layout, the model should be able to consider all possible arrangements of components and piping, which results in a combinatorial problem which usually is very complicated to solve. These possible arrangements can be modeled though the use of integer variables, which allow for the different combinations that may arise with respect to relative positions between components and possible rotations of equipment.

3. Case study

In order to optimize the tissue manufacturing plant, the model proposed by GUIRARDELLO (1993, 2005) was employed. The model is formulated as a mixed integer linear programming, in which the objective function to be minimized includes:

- ✓ costs related to the plant size;
- ✓ cost of equipment supports;
- ✓ cost of piping

and is subjected to the following restrictions:

- ✓ do not superpose pieces of equipment;
- ✓ keep safety distance among pieces of equipment;
- ✓ allow conceptual equipment rotation,

so that the optimization of the problem results in an economical layout that guarantees safety and easy access to plant components.

The tissue paper plant considered in this paper had 15 main components, which are described in Drummond et al (2005).

4. Results and Discussion

The model proposed by Guirardello was implemented with GAMS/CPLEX 7.5, and solved by a Sun Enterprise E250 400 MHz workstation. Initially the model was tested for the problem in its original structure with 15 components, and the algorithm was allowed to reach the best solution. However, the computational time was too high, without finding the proven optimal solution (with gap zero) in the branch-and-bound search. Therefore, it was decided to reduce the size of the problem to 10 components, through the grouping of some equipment. This grouping was not arbitrary, but it was based on the requirement of some components to be necessarily close to other components, as for example, bombs to the side of tanks. In Table 01, we present the number of equations and variables that resulted from the optimization. In Table 02 it is presented the optimal values, using two search strategies (best-bound and depth-first), which resulted in identical results.

Table 01 - Number of equations and variables required

Blocks of Equations	25
Blocks of variables	24
Non zero Elements	3.349
Single Equations	783
Single Variables	738
Discrete Variables	309

Table 02 - Results for optimal costs using two search strategies: best-bound and depth-first.

Optimal Costs	
best-bound and depth-first searches	
Ground	17,583.00
Support	58,207.72
Pipines	4,984.86
Z Optimal	80,739.35

Table 03 presents the required computing time using the best-bound search, as well as the number of iterations necessary and the amount of inspected nodes in the branching-and-bound method.

Table 03 - Results for best-bound strategy.

best bound	
Time	38278 s
Number of iterations	46
Nodes	6235023

In table 04, the dimensions and center positions (x, y and z directions) of each piece of equipment are presented, from the optimal solution found using best-bound search.

Table 04 – Dimensions and Final Position for each component

Components	Ai (m)	Bi (m)	Ci (m)	Xi (m)	Yi (m)	Zi (m)
1	3.00	3.00	6.00	15.70	11.10	3.00
2	4.00	6.50	5.00	8.20	11.10	3.00
3	0.50	0.45	1.50	7.95	5.625	8.25
4	0.50	1.90	0.90	8.45	4.55	11.95
5	4.50	3.00	6.00	11.45	3.85	3.00
6	3.30	1.20	1.30	5.60	3.85	0.65
7	0.50	1.10	0.90	5.15	3.85	9.95
8	2.50	2.00	5.00	1.50	4.85	3.00
9	1.60	2.00	2.50	1.00	0.80	1.25
10	21.50	3.30	5.50	10.75	17.25	2.75

After obtaining the optimal results from GAMS, the Autocad 2004 software was used to draw the pictures with tissue plant equipment locations. Figures 02 and 03 show the equipment for two different views.

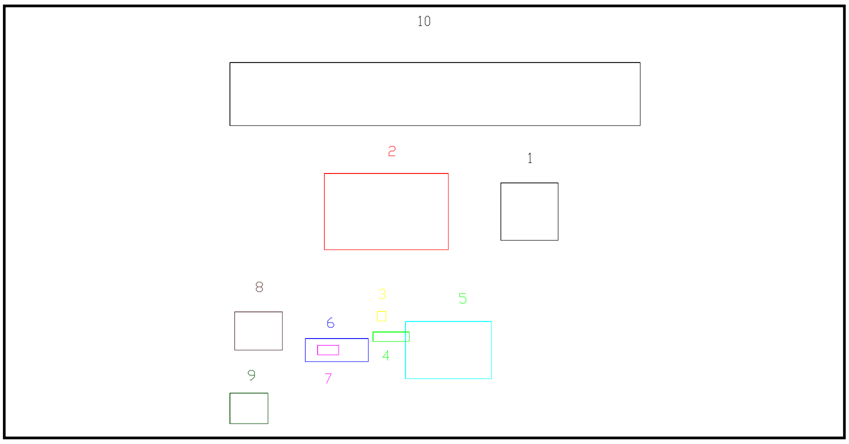

Figure 2 – Top View

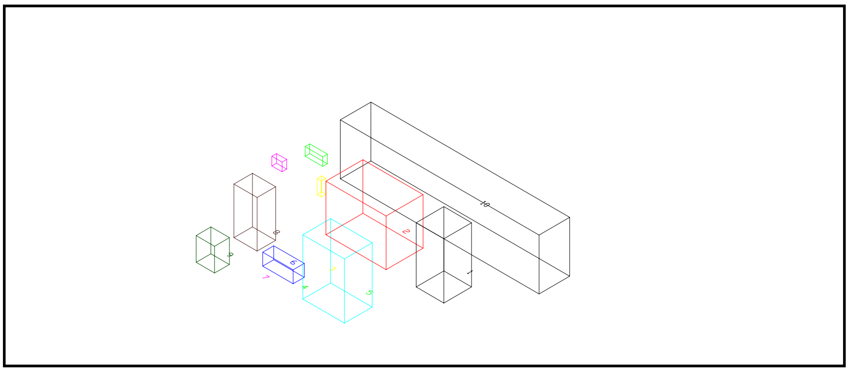

Figure 3 – Isomeric SE view

5. Conclusion

The objective of this work was successfully obtained with the best placing of the pieces of equipment for a tissue manufacturing plant, which is of importance considering that some of the components are quite large and can not b moved around. Size of the plant, equipment support and piping costs were minimized. The algorithm employed was very efficient. The required computing time was acceptable, despite the great amount of integer variables. The grouping of components allowed a reduction in the size of the problem, without affecting the optimal solution.

6. References

ANDERSON, F. V. Plant layout. In: Kirk-Othmer, Encyclopedia of Chemical Technology, 3rd. ed., 18, pp. 23-43, 1982.

BUSH, M. J. and WELLS, G. L. Optimum plant layout scores on maintenance, operation, safety. Process Engineering, 53 (9), pp. 135-137, 1972.

BROOKE, A., KENDRICK, D. and MEERAUS, A. GAMS: a user's guide. San Francisco: The Scientific Press, 1988.

DRUMMOND, Daniela Medeiros Devienne; GUIRARDELLO, Reginaldo. Optimization of Tissue paper equipment layout using MILP. In: ICHEAP 7, 2005, Giardini di Naxos-Italy, 2005.

FRANCIS, R.L. and WHITE, J. A. Facility layout and location: an analytical approach. New Jersey: Prentice Hall, 1974.

GARCIA, CARLOS ALBERTO. Plant Layout Process. Fundacentro; São Paulo 2ª Edição, 1980.

GUIRARDELLO, R. Optimization of Process Plant Layout. Ph.D. Thesis, University of Wisconsin, Madison, USA, 1993.

GUIRARDELLO, R., Ross E. Swaney, Optimization of process plant layout with pipe routing, Comp. and Chemical Eng, 30, pp. 99-114, 2005.

HOUNSELL, MARCELO DA SILVA., Plant Layout, 1999.

KAURA, M. L. Plot plans include safety. Hydrocarbon Processing, 59 (7), pp. 183-194, 1980.

KERN, R. How to manage plant design to obtain minimum cost. Chemical Engineering, 84 (11), pp. 130-136, 1977.

KERN, R. Arranging the housed chemical process plant. Chemical Engineering, 85 (16), pp. 123-130, 1978.

MECKLENBURGH, J. C. Process plant layout. New York: Halsted Press - John Wiley & Sons, 1985.

OLIVÉRIO, J.L. Projeto de Fábrica IBLC, São Paulo, 1985.

RARDIN, R. "Optimization in Operations Research"- Prentice Hall, pp. 609-613, 1998.

SCHEY, JOHN.A. Introduction to Manufacturing Processes. Mc Graw-Hill Book Company, Second Edition, 1987.

ULRICH, G.D. A guide to chemical engineering process design and economics. New York: John Wiley & Sons, 1984.