# The Application of Risk Assessment to Facilities Planning: A Synthesis of Risk Assessment Methods and Layout Design Models

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## ABSTRACT

The layout planning of facilities constitutes an important issue to be faced by a company. While the main concern with the facilities layout planning is to reduce the cost of material handling, the layout of a facility plays a major role in the safety and productivity of operations. Many approaches have been presented for planning facilities layouts; however, OH&S issues were often ignored in most previous studies. This is despite the need for preventing or minimizing accidents through proper facilities layout planning.

Moreover, methods of identifying hazard and assessing risks, which may exist in a company, can take many forms. Each method offers a different perspective and with it differing strengths and weaknesses. Depending on the system design of the company and the user interactions with it, one or more methods can be used to assess risks. Therefore, which particular method best suits for risk assessment, would depend on the application.

Due to the diversity of the tools for facilities planning and risk assessment, this paper surveys the facilities layout planning models and risk assessment methods. Different methods, used by companies as the risk assessment tools, are presented. Most of the conventional algorithms and techniques for solving facilities layout problems are also reviewed and their characteristics are commented. This survey will pave the way to the integration of these two types of tools, i.e. having a facility planning tool which incorporates OH&S. General remarks and tendencies are reported for merging these two research fields.

## 1 INTRODUCTION

Safety management and risk assessment receive growing attention as companies seek to implement methods in order to maximize the use of safety and optimize the use of financial resources. The risk assessment process is flexible and scalable as exposed in real world applications. However, it is likely that the diversity of risk estimation tools, which are available to carry out the risk assessment, be attributed to the needs of companies. Therefore, a risk assessment method which successfully used in one company does not necessarily meet the requirements of the other [1].

Likewise, facilities layout planning, as an important research topic in physical system design, has recently received much attention from production engineers. This is partly due to the increased global competition in manufacturing and the efforts to reduce manufacturing costs [2]. The majority of previous research in facilities layout planning has focused on optimizing movement costs, site costs, and qualitative preferences; the relationship between facilities layout and safety concerns has not been considered extensively in developing the methods and models. This paper attempts to present a state-of-the-art review of risk assessment methods, models of facilities layout planning, and characteristics of each of these tools. This is the first step in integrating facility planning and risk assessment.

# 2 FACILITIES PLANNING MODELS

Where to locate facilities and the efficient design of those facilities are important and fundamental strategic issues facing any manufacturing industry [3]. Traditionally, planning a layout starts by making a layout diagram for the facilities, which consists of different activities connected to each other. The design proceeds by trial and error until a compromise is reached, which more or less satisfies all the known factors and restrictions [4]. Therefore, a layout is traditionally developed using relationships among the various facilities, based on the judgement of experts who decide the importance and strength of relationships between each pair of facilities. However, the decision of experts is vague and usually based on many quantitative or qualitative considerations pertaining to the desired closeness or relationships among the facilities; e.g. flow of materials between facilities or ease of supervision of employees [5].

Moreover, the main objective of the facilities layout problem is to minimize the materials handling cost, which is a quantitative factor. However, qualitative factors such as plant safety, flexibility of layout for future design changes, noise and aesthetics need to be considered as well [6].

## 2.1 Formulations of Facilities Layout Problem

The facility layout problem considers the assignment of facilities to locations so that the quantitative or qualitative objective of the problem is optimized [7]. The quantitative objective is to minimize the material handling cost, while the qualitative objective is to maximize the subjective closeness rating by considering vital factors such as safety, flexibility, noise, etc. [8] The facility layout problem is one of the best-studied problems in the field of combinatorial optimization, where more particularly it has been modelled as a: (1) quadratic assignment problem (QAP), (2) quadratic set-covering problem (QSP), (3) linear integer programming problem, (4) mixed integer programming problem (MIP), and (5) graph-theoretic problem.

Although these approaches hold much promise, they have drawbacks. Even a powerful computer cannot handle a large instance of the QAP problems. The disadvantage of the QSP approaches is that the problem size increases as the total area occupied by all the facilities is divided into smaller blocks. Computational experiences for linear integer programming models indicated that they are not suitable for problems with more than nine facilities. For MIP, only facilities layout problems of size six or less are optimally solvable. Similar to QAP approaches, unequal area problems of even small size cannot be solved optimally for graph-theoretic problems [7, 9].

## 2.2 Analytical Solution Methods

Since the late 1950s a number of algorithms have been developed to solve the facility layout problem, classified as:

1. Optimal algorithms: these algorithms, which were developed to solve QAP, fall into two classes: branch and bound algorithms and cutting plane algorithms. The common disadvantages of the optimal algorithms are the high memory and computer time requirements, while the largest problem solved optimally is a problem with 15 facilities. This has encouraged researchers to use sub-optimal algorithms.
2. Sub-optimal algorithms: many researchers developed sub-optimal algorithms to also deal with QAP. These algorithms are classified as: construction algorithm (where a solution is constructed from scratch), improvement algorithm (where an initial solution is improved), hybrid algorithm (combination of two optimal or sub-optimal algorithms), and the graph theoretic algorithm [7].

The major drawbacks of the aforementioned approaches lie in the fact that the search for the best layout is not very efficient and the multi-objective nature of the facilities layout problems are not considered [10]. Many studies focussed on new and recent developments rather than conventional approaches to overcome these drawbacks. Intelligent techniques are presented as new advancements to tackle the problem.

3. Meta-heuristics algorithms: the most well-known of these systems are neural networks, genetic algorithm, simulated annealing, tabu-search, and ant colony optimization;
4. Expert systems;
5. Fuzzy systems; and
6. Intelligent hybrid systems.

Table 1 illustrates some of the analytical solution methods used for facilities layout problems.

*Table 1. Survey of analytical solution methods for facilities layout problems*

| Model | Technique | Objective | Comments |
|---|---|---|---|
| PLANET [11] | Construction | Flow cost | Starts at centre, 2 facilities located at once |
| FATE [12] | Construction | Flow cost Closeness | Extension to MAT, two criteria to rank facility pairs |
| MAT [13] | Construction | Flow cost | Allows user to assign facilities to any desired location |
| ALDEP [14] | Construction | Closeness | Randomly selects a facility, starts at upper left corner |
| SHAPE [15] | Construction | Flow cost | Based on generalized assignment problem |
| FLAT [16] | Construction | Flow cost | Facilities of unequal areas, low compute time, good quality results |
| CORELAP [17] | Construction | Closeness | Selects first facility depending on total closeness value |
| FLAG [18] | Construction | Flow cost | Interactive, considers various shapes, realistic distances between facilities, the user can modify the layout as desired |
| RMA [19] | Construction | Closeness | Similar to CORELAP, start at centre |
| Linear Placement [20] | Construction | Flow cost Closeness | Only for facilities of equal areas, single and multi-storey buildings |
| HC66 [21] | Construction | Flow cost | Uses criteria of Vogels' approximation in TP |
| INLAYT [22] | Construction | Flow cost | User can modify the output by using a light-pen |
| LSP [23] | Construction | Closeness | High computational efforts, similar to ALDEP, flexibility |
| CRAFT [24] | Improvement | Flow cost | Up to 40 facilities, does not perform well for facilities of unequal areas, uses 2- and 3-way exchanges for smoothing irregular shapes |
| TSP [25] | Improvement | Flow cost | Similar to CRAFT, executes selective pairwise exchanges, reduces compute time |
| FRAT [26] | Improvement | Flow cost | Only for facilities of equal area, good quality results, uses principles from e.g. HC63-66, CRAFT, COL |
| H63 [21] | Improvement | Flow cost | Only pairwise exchanges between adjacent facilities, only for facilities of equal areas, based on a move desirability table |
| HC 63-66 [21] | Improvement | Flow cost | Limits the exchanges only to facilities which lie on a horizontal, vertical or diagonal line, only for facilities of equal areas, a modification of H63, allows exchange of non-adjacent facilities. |
| Revised Hillier [27] | Improvement | Flow cost | Uses H63, considering 4-way perturbations, produces solutions at least as good as H63, more computation time than H63 |
| COFAD-F [28] | Improvement | Flow cost | Considerable amount of compute time, flexibility, uses COFAD |
| COFAD [29, 30] | Improvement | Flow cost | MHS selection, uses CRAFT, jointly considers layout and material handling system, more realistic layouts |
| COL [31] | Improvement | Flow cost | Good quality solutions, twice as fast as HC66, less memory storage |
| MICROLAY [32] | Hybrid | Flow cost | Manual adjustments for e.g. aisle space, interactive, a combination of construction and improvement |
| DISCON [33] | Hybrid | Closeness | Dispersion phase provides good starting points, difficult to justify the outcome, uses a two-phase algorithm of dispersion-concentration |
| KTM [34] | Hybrid | Flow cost | Uses 2- and 3-way exchanges, a combination of construction and improvement, very good results within very little computer time |
| FLAC [35] | Hybrid | Flow cost Closeness | Has three stages, a combination of construction and improvement |
| Wheel Expansion [36] | Graph Theoretic | Adjacency | Similar to Deltahedron |
| Branch and Bound [37] | Graph Theoretic | Adjacency | Obtain optimal solution, a require maximal planar graph |
| Deltahedron [37] | Graph Theoretic | Adjacency | Avoid the testing of planarity |
| FADES [38] | Expert System | Flow cost Closeness, Materials handling cost | Knowledge-based approach, for solving general facility design problems, selecting equipment that meets the required technology level and performing economic analysis, written in PROLOG |
| IFLAPS [39] | Expert System | Adjacency | In FORTRAN, does not involve paired comparisons between departments or the overall, relationship between various facilities |
| KBML [40] | Expert System | | For machine layout in automated manufacturing systems, a forward-chaining inference strategy is utilized |
| [41] | Neural Network | | Near-optimum parallel algorithm, for an N-facility layout problem, BEING capable of generating better solutions over the existing algorithms for some of the most widely used benchmark problems |

| | | | Pharmaceutical industry, allows the user to select the most important objectives in each particular layout design, outperforms all existing computer layout algorithms such as CRAFT, CORELAP and BLOCPLAN as well as human designers in maximizing the throughput rate and minimizing the traveling time/trip |
|---|---|---|---|
| [42] | Genetic Algorithm | | |
| HOPE [43] | Genetic Algorithm | | For solving single-floor facility layout problem, considered departments of both equal and unequal sizes, results indicated that GA might provide a better alternative in a realistic environment where the objective is to find a number of reasonably good layouts |
| MULTI-HOPE [44] | Genetic Algorithm | | Multiple-floor layout problems, extends HOPE algorithm, averagely gives a better solution than existing multi-floor layout algorithm |
| [45] | Fuzzy System | Flow cost Closeness | AHP is used to find the weights of qualitative and quantitative factors affecting the closeness rating between departments, a modified version of CORELAP (FZYCRLP) is used |
| [46] | Fuzzy System | Flow cost Closeness | Considers organizational links optimisation. A linguistic pattern approach for multiple criteria facility layout problems. |
| FLEXEPRET [47] | Intelligent Hybrid System | | A fuzzy-integrated expert system, generates the best layout that satisfies the qualitative as well as the quantitative constraints on the layout problem, VP-Expert is used |
| [48] | Intelligent Hybrid System | | A neural expert system, creates effective multi-bi-directional generalization behavior, goal-driven layout design experience |

## 3 RISK ASSESSMENT METHODS

Risk assessment methods are proposed by organizations that are involved in the safety of industrial machines (e.g. standardization bodies, OH&S associations) while some companies have established their own methods and tools of analysis [1]. The large number of tools proposed and used indicates that there is no single universal approach for risk assessment [49]. Although risk assessment methods have existed in various forms for many years, interests have recently been increased because of factors such as time, cost, competition, international influences, capturing knowledge, product liability, lack of standards, schedule control, and customer requirements [50]. Despite the fact that there are different tools and methods for assessing risk, it may not be an easy task to choose the tool that best adapted to the needs of each company. Table 2 addresses the common families or types of risk assessment methods.

*Table 2. Risk assessment methods for facilities layout problems*

| Types | Description | Comments |
|---|---|---|
| Risk Matrix [51] | A multidimensional table for combination of any class of severity of harm with any class of probability of occurrence of that harm. | Tools can have 2 or more parameters (e.g. severity of harm and probability of harm). |
| Risk Graph [52] | A tree structure that enables risk to be determined for each safety function. | Usually four parameters are used: consequence of hazardous event, frequency of presence in hazardous zone and potential exposure time or occupancy, probability of avoiding hazardous event, probability of unwanted occurrence. |
| Numerical Scoring [53] | Numerical scoring tools have 2-4 parameters that are broken down into a number of classes in much the same way as risk matrices and risk graphs. | Parameters are: severity, probability of exposure, avoidability and degree of exposure, numerical values ranging 1-20 are used instead of qualitative terms. |
| Quantified Risk Assessment (QRA) [54] | It is a top-down approach that answers three questions: (1) what can go wrong, (2) how likely is it, and (3) what are the consequences. | Risk is expressed as annual frequency of death of individuals, can be subjective and prone to mistakes. The use of small numbers to express risk make believe of high precision whereas there can be considerable uncertainty in the data used to calculate the risk. |
| Preliminary Hazard Analysis (PHA) [55] | It is primarily an analysis of hazard detection and the most important examination of the state of safety of the system. | Best conducted early in design process, traditionally used to identify hazards although often extended to assess risks and reduce them. |
| Event Tree Analysis (ETA) [56] | ETA starts with an event such as malfunctioning of a system, process, or construction. The predictable accidental results, sequentially propagated from initiating event, are presented graphically. | Representing system safety based on the safeties of sub-events, consists of an initiating event, probable subsequent events and final results caused by the sequence of events. |

| | | |
|---|---|---|
| Fault tree analysis (FTA) [55] | A top down symbolic logic technique that models failure pathways within the system, tracing them from a predetermined, undesirable condition or event to the failure or fault that may induce it. | Best applies to cases with: large perceived threats of loss, complex or multi-element systems or processes, already-identified undesirable events and indiscernible mishap causes. Depicts functions that lead undesired outcomes, provides both qualitative and quantitative analysis, provides insight into the system behaviour. |
| Cause Consequence Analysis (CCA) [57] | It is a blend of fault tree and event tree analysis that ccombines cause analysis (from fault trees) and consequence analysis (from event trees). | Identifies chains of events causing undesirable consequences. |
| Management Oversight Risk Tree (MORT) [58] | A comprehensive analytical procedure that provides a disciplined method for determining systematic causes and contributing factors of accidents in an existing system. | Similar to fault tree analysis, used as a non-quantitative safety tool. |
| Failure Mode and Effects Analysis (FMEA) [55] | Identifies potential failure modes that could lead to incidents. It breaks down designs into components and subcomponents, and systematically evaluates the potential for and effects of individual failures by focusing on how they can lead to hazards or negative consequences. | Most familiar for design engineers, widely used in automotive and medical devices industries to evaluate system failure, well suited to situations where engineers are unsure what problems might occur or how small problems could lead to larger ones, useful in determining which of several potential problems should receive priority attention. |
| Failure Mode, Effects and Criticality Analysis (FMECA) [59] | An analysis method wherein criticality analysis for a quantitative assessment is performed taking the effect of the failure mode on the system as the failure grade in addition to the FMEA. | The two methods to analyse critically are quantitative analysis and qualitative analysis. |
| Structured What-If Technique (SWIFT) [55] | A structured approach to identify potential hazards and evaluating their consequences. | Considers deviations from the design, construction, modification, or operating intent of a process or facility. |
| Hazardous operations (HAZOP) [55] | A formal procedure to identify how a process might fail and how such failures can be avoided. Conducted at the end of the design process. | Not strong or necessarily effective in prioritizing effects of the failures, does not study the relative effectiveness of proposed corrective actions. |

## 4 CONCLUSION

Methods of analysing risks as well as the models for solving facility layout problems can take many forms. Some of the most frequently used tools were exposed in this paper. Each method offers a different perspective and with its differing strengths and weaknesses. While, a new trend in designing plant layouts consists of extending the layout formulations with safety issues, the cited models for solving the layout problems do not directly include safety issues. Though, with the mixed integer linear programming models that have been proposed to reduce financial costs, e.g. [60-63], modelling safety issues unavoidably end up in these models. Moreover, artificial intelligent techniques (particularly genetic algorithm and expert system) have been proposed which consider both quantitative and qualitative factors, including safety and ergonomics; e.g. [64-66].

Further research would aim to propose a methodology by which facility planning models and risk analysis tools can be integrated together in order to better meet the safety requirements of companies. In this concern, a facility layout problem can be formulated as a mathematical model while considering OH&S issues as the constraints of the model. The OH&S issues can be taken out from the quantitative and qualitative parameter of one or more of the risk assessment methods. The developed mathematical model will thereafter be solved through using an analytical solution method. By this means, safety issues would be considered as an important factor as cost, closeness, material flow, flexibility, or material handling system concerns, in the facility layout problems.

The research can be expanded by an actual study of considering OH&S issues while planning the layout of an industrial facility. The practical tools that are already used by these facility planners as well as the safety factors that they consider would support the aforementioned developed model. Furthermore, collaborations with industrial partners will permit improving their actual methods in two ways; by include safety aspects in facilities planning methods as well as considering machines positioning in security evaluations. The long term objective is to improve the health and safety of the workforces, while recuperating the efficiency of the industrial facility.

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