DESIGN AND OPTIMIZATION OF A FACILITY LAYOUT PROBLEM IN VIRTUAL ENVIRONMENT

Fabio Fruggiero
ffruggiero@unisa.it
University of Salerno
Department of Mechanical
Engineering
Via Ponte Don Melillo, 1
84084 - Fisciano (Sa)
ITALY

Alfredo Lambiase
lambiase@unisa.it
University of Salerno
Department of
Mechanical Engineering
Via Ponte Don Melillo, 1
84084 - Fisciano (Sa)
ITALY

Fabio Negri
fab.negri@libero.it
University of Salerno
Department of Mechanical
Engineering
Via Ponte Don Melillo, 1
84084 - Fisciano (Sa)
ITALY

ABSTRACT

Productivity improvement, due to high competition on global marketplace, requires a concurrent/reverse engineering approach to layout design, simulation and optimization in as short as possible times. Besides, a facility layout problem can be viewed as a combinatorial optimization problem solvable through heuristic methodologies.

Designers, engineers and managers needs automated tools to effectively analyze layout and define an optimal configuration. Central to success is the integration of multi objective mathematical procedures with robust design techniques and virtual representation/validation in stereoscopic real scale.

Flow analysis, plant design and optimal 3-D layout representation, with virtual environment validation, are the objects in our facility layout approach. In a Virtual Reality environment, using Axiomatic Design, it is possible to analyze alternative design configurations with little efforts and short time, obtaining improvements in communication, savings in changes and assuring design integration with computer tools.

Encouraged by the big interest on Virtual Reality abilities, the paper presents an innovative robust design application based on a Rectangle-Packing placement optimization procedure with Virtual Reality environment validation of a real flow shop production process.

Keywords: Virtual Reality (VR), Virtual Environment (VE), Axiomatic Design, Rectangular-Packing placement (RP).

1 INTRODUCTION

Product innovation, production development and shorter and shorter Time to Market are crucial aspects to face with customers demands and increasing competition on global marketplace. Market timing and customer requirements are very important in order to meet the market window.

In a classical production environment, the production planning system assigns a list of pending orders to certain resources that must be processed and scheduled in order to optimize a fixed objective function. We would like to reply demand like in just in time approach. As a consequence, enterprises feel the need to timely respond to customer demands, reaching for higher efficiency on new production processes, higher quality of product so have to operate in optimal planning and well designed conditions. To these ends, production system and process are designed integrated with product shape in a concurrent/reverse engineering approach. In this circumstances, a well suited robust Facility Layout Design (FLD) is considered to be an important issue facing with productivity rate. A robust layout is one that is good for wide variety of demand scenarios.

Flow analysis, plant design and optimal 3-D stereoscopic layout representation are thinking of central keys to success. Designers, engineers and managers need tools and methodologies to analyze and define optimal-robust layout configuration and implement it in as short as possible time.

A general facility layout problem is concerned with the physical organization/allocation of a production system. It can be considered belonging to the class of NP-hard problems and it is described like the generalization of a Quadratic Assignment Problem (QAP) in the sense that we have to allocate, in same way, M facilities to M locations (where M represents the problem size). In a facility layout problem we are going to find a criteria, which maximize/minimize some objectives (quantitative and qualitative ones like production time, flexibility in volume and variety, allocation space, product quality, costs etc…), in order to find the most efficient arrangement of M indivisible departments with unequal area requirements within a facility [1]. Therefore, any algorithm layout approach can be obtained in an amount of time which is bounded by a polynomial in the size of the problem, and optimal solutions are proposed and, therefore, accepted. We are thinking of qualitative and quantitative criteria inherent with a multiple objective problem.

This paper presents a decision making methodologies that implements a robust design application based on Rectangular-Packing-Based placement optimization procedure [2] within a Virtual Reality environment and across Axiomatic Design [3].

To cope with the difficulties on the development of a facility layout optimization algorithm and so generate layout alternatives

we will implement an Analytic Hierarchy Process (AHP) like mathematical programming model or simulation models.

The axiomatic design is used to described the implemented flow shop (it s regarded to an automotive factory plant layout) through mapping between Functional Requirements vector {*FRs*}[1], that represents the goal of the designed process, and Design Parameters one {*DPs*}, that satisfies the needs in customer and production rates.

The mixture of Axiomatic Design, Robust Design, Virtual Reality contains basic principles that will improve productivity (in saturation rates and throughput) creativity and ergonomy and quality. This paper presents a decision making methodology based on Axiomatic Design (AD) and Virtual reality Environment (VE) representation\validation which uses both qualitative and quantitative criteria for evaluating Facility Layout Design (FLD).

While the first part of our paper is related with the mathematic formulation of the facility layout problem, the central part focuses on the axiomatic design implementation in Virtual environment. The last part of this work presents the improving performances of the model implemented in a real automotive environment. We will deal with numerical improving in balancing and process layout optimization.

2 PROBLEM STATEMENT: THE MATHEMATICAL FORMULATION OF THE FACILIY LAYOUT PROBLEM

The facility layout problem is considered like a combinatorial optimization problem, belonged to the class of NP-hard problems [4]. It is describing across Quadratic Assignment Problem (QAP) theory [5]. It has been variously referred to as Facility Layout design (FLD), Layout Design (LD) problem, plant layout, layout optimization, block placement etc… so we will use, in our characterization, these as synonymous. The concept of FLD is usually considered as a multiple objective problem and its solution is often challenging and time consuming. Facility layout problem usually involves the arrangement of department to optimize the distance traveled by unit of products, people, flow, information etc….

The QAP formulation assigns every departments to one location and at most one department to one location. The problem can be described as an optimizing assignment of settled locations to facilities with given cost between locations and flows between facilities. It is a generalization of several problems [6] and was stated for the first time by Koopman and Beckman [7].

It can be applied in a variety of disciplines including web sites and newspapers designs, nest problem in cutting, urban planning and certainly flow assessment in industries etc….

To develop an effective facility layout evaluation procedure we need the consideration of qualitative and quantitative criteria. Because optimal methods are limited in problem dimension, it has been developed sub optimal algorithm that can solve this problem. Well known algorithms, based on grids (and flow

between them) representation, have been developed to solve the Layout Design problem. There are:
- optimization algorithm like ADELP, CORELAP, CRAFT;
- optimization procedures that implement general heuristic/meta-heuristic algorithms based on fuzzy Logic and/or Simulated Annealing theory and/or Genetic Algorithm and/or Ant Model and/or Artificial Intelligent formulation, etc….

Our solution of the QAP is obtained by a Rectangular Packing algorithm (RP) based on fuzzy set theory like a robust implementation procedure [8]. Our approach starts the design of optimal solution with a near-optimal block layout based on facilities' flow relationship and\or data's intensity. An analytic hierarchy process is, then, applied in order to aim the optimal solution for this multicriteria decision problem. It was implemented by the help of an user -friendly application package. In a Rectangular-Packing-Based implementation each task is represented by rectangle, put in gridded space. We are given a set on M rectangles $R = \{1, 2, ..., M\}$ where each area (i) is specified in width (w_i) and height (h_i).

If we search the x and y coordinates of each rectangle, since the number of solution is uncountably many. Utilizing RP algorithm based on fuzzy set the solution of a packing has to be defined to considered wires. Therefore various constraints and fuzzy relationship set have been adopted.

Figure 1*: Space information in the implemented Facility Layout Design problem*

The Layout Design is considered to be a NP-hard problem although we introduce hard and soft constraints[2] and we fix the minimum bounding (like real number) of each rectangle of a packing (Fig. 1).

Trough a Rectangle-Packing-Based placement we consider, firstly, a set of rectangular, representing each department/task into a fixed enclosing rectangle (Fig. 2), and then, implementing an iterative procedure based on user defined relationship chart between areas/UTE, we search for minimum allocation space of enclosing rectangles, with no overlap.

Therefore, the problem is to pack a given set of M rectangles without overlap so the cost, like allocation space and/or distances, is minimized. A solution called packing represents the feasible

---

[1] In this characterization each vector of one dimension value will be expressed in a curly bracket while the vector of two dimensions value (matrix) will be pointed with a squared bracket.

[2] Hard constraints are physical one, soft constraints are those related to human factors e.g. relaxation.

location of each rectangular. The solution is determined considering centroid department distances.
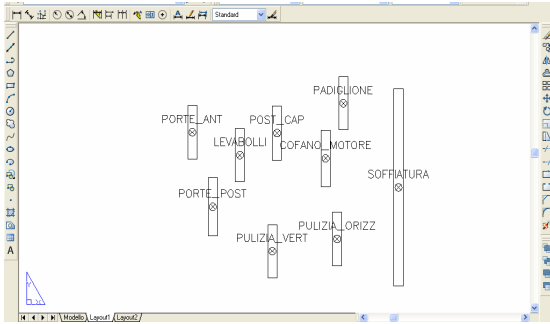

Figure 2: *The implemented procedure starts with a casual disposition of UTE.*

The output of this problem is a block layout, which specifies the relative location of each department and includes flow-line layout, machine allocation, I/O point location etc….

Generally, in any layout design problem the efficiency of a solution is valued in terms of material handling costs [9] so the solution is determined, according to constraints, in order to draw up machines and/or departments with more mutual flow. Formally the problem can be defined by three $M \times M$ matrix (interdepartmental flow matrix (P), unit cost matrix (C) and distance matrix (D)), by a M dimensional vector (F) of internal costs and by a minimization function (C_{min}^{*}) (Eq.1).

The principle is that the material handling costs increases with the distance the unit load must travel.

$$C_{min}^{*} = \min(C) = \min\{\sum_{i=1}^{M} F_i + \sum_{i=1}^{M}\sum_{j=1}^{M}(P_{ij} \cdot C_{ij}) \cdot D_{ij}\} \qquad (1)$$

Where:

C_{min}^{*}: represents the minimization function of total interdepartmental and intradepartmental material handling costs;

F_i: is the fixed cost of the generic activity/machine i;

P_{ij}: is the flow from department i to department j;

C_{ij}: is the cost to move one unit load one distance unit from i to j department;

D_{ij}: is the distance from department i to department j.

Is important to note how, in our characterization that search the minimum of Eq. 1, the optimal solution isn't influenced by the fixed cost of department i (F_i).

If the problem employs in a generic environment, as multifloor environment, we have to considered vertical distances and unit load costs (marked with a "V" pick) and horizontal ones (marked with a "O" pick) so the optimization function becomes the sum of two terms (EQ.2):

$$C_{min}^{*} = \min\{\sum_{i=1}^{M}\sum_{j=1}^{M}(P_{ij} \cdot C_{ij}^{V}) \cdot D_{ij}^{V} + \sum_{i=1}^{M}\sum_{j=1}^{M}(P_{ij} \cdot C_{ij}^{H}) \cdot D_{ij}^{H}\} \ (2)$$

This representation implies to choose an optimal solution between $\dfrac{M!}{M-1}$ ones.

One of the uncountable solution is sketched is figure 3 where the flow analysis has developed a flow shop solution.
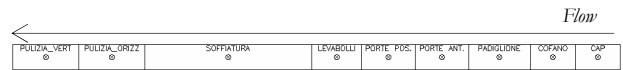

Figure 3: *One of the solution outputs (Flow layout).*

In the next part of this paper we will present our approach to the problem with axiomatic design implementation within a virtual reality environment.

3 THE AXIOMATIC DESIGN WITHIN VIRTUAL ENVIRONMENT FOR A REAL FACILTIY LAYOUT PROBLEM IMPLEMENTATION

The Facility Layout design, like a process design phase, represents a decision process. To obtain skill in realizing process we have to take in consideration important targets and so to make decisions. Necessary to this end is not only an appropriate problem mathematical representation but also a suitable design procedure. We need to implement a target oriented decision approach replying to points linked up what and how we want to gain. So, we recognize in the axiomatic design approach this end.

The Axiomatic Design is considered as oriented decision procedure, based in structured thinking, helping the authors to design a layout model complied with defining targets and marking decisions. It establishes guidelines allowing us to identify the process layout. Productivity, quality and decision theory are laid down upon an axiomatic design approach. The layout design solution is then determined thanks to RP placement procedures with a fuzzy set relationship and it is validated across a VE implementation.

Our facility layout solutions is based on a structured decision-making approach that takes in consideration functional requirements and designed parameters by an axiomatic approach. The design parameters, chosen under the constraints of the implemented process, are tuned in order to meet functional requirements. Our implementation has been successful in combining two powerful strategies Axiomatic Design and Virtual Reality. The representation in virtual computer-generated environment is used like a validation of final layout solution. A RP placement algorithm with QAP formulation, implemented under a software package and based on fuzzy set theory, has been adopted to constitute the layout alternatives (section 2).

Alternatives layout solutions are generated using qualitative and quantitative performance data (such: space, material handling vehicle utilization, material handling cost, distances between facilities etc…) in order to define the most robust layout. Then, the alternative layout solutions are detailed by means of the change in Virtual Reality environment.

3.1 THE AXIOMATIC PROBLEM FORMULATION

The FLD is a complex problem that requires advanced design techniques and decision aid tools. Introduction of quality aims, production requirements and customer and worker demands, in the early stages of design, is essential to improve industrial productivity and efficiency and effectiveness of the process design. If we consider a general design activity, its traditional scope has been defined as direct mapping between functional requirement to physical product/production/system specifications [10].

There are a lot points, based on manufacturability and defined like Designed Parameters {DPs}, whose are thought high points to successful considering the endless possibilities of connecting manufacturing facilities and their production capabilities. The Axiomatic Design approach, of our Facility Layout Design model, is applied like preliminary background to defined one flow-layout solution in Virtual Reality (VR). The Virtual reality Environment (VE) is put on to virtual validate workplaces, to modify the layout design and the scheduled tasks, in order to realize the specified Functional Requirements {FRs}. The Virtual Reality environment offers rapid, realistic and easy modifiable creation of layout configuration utilizing the principles and methodologies of Axiomatic Design.

The key concept of the axiomatic design procedure is that {DPs}, created in the physical domain and expressed like Process Variables {PVs}, have to be formulated in order to satisfy the {FRs}, step up in the functional domain.

The dimension of DPs vector defines the entity of problem's parameters.

$$\{FRs\} = [DM]\{DPs\} = [RP][VR]\{DPs\} \qquad (3)$$

In our model, a zigzagging and dealing between domains with correlation of the Design Matrix (**DM**), as sum of two ones (the first related to the implementation of a RP placement procedures (**RP**) and the second one to an expert analysis in virtual environment (**VR**) (Eq.3)), takes place to make robust layout solution.

The zigzagging takes place between two domains: the functional and physical one [11].

$$DM_{ij} = \frac{\partial FR_i}{\partial DP_j} \qquad (4)$$

The direct connection between functional domain and physical one is fulfilled to conceptualize and to have a problem's mapping (Fig 7). Besides, the direct connection between physical domain and functional one defines the next level functional value to analyze (Fig.7).

Layout design are predicated on the assumption that there are material handling and vehicle alternatives to choose.

Axiomatic Design gives us a possibility to describe a following principles' road map. It covers a collection of fundamental principles that are important to know and follow in the design on manufacturing layout system primarily in the conceptual phase.

The axiomatic design is the procedure to determined which important functional requirements have to regard in our manufacturing system. Factory automation, material handling costs, shape ratio, flexibility in volume and variety, quality etc… are some of the parameters we took in consideration in our implemented model.

Each element in **DM** domain represents a constraint in design (Eq.4). Naturally, in order to satisfy the Independence Axiom (axiom 1: maintain the independence of {FRs} in the selection of design parameters {DPs}) the two matrixes that compose the **DM** one, in our decoupled approach, have to be triangular matrix of the same type (Eq.5). In our approach the {FRs} are defined in a dialogue with customer and production market and internal factory production policy including tolerances from standard or target value.

The {DPs} includes the characteristic of the process system to produce our product (fig. 7).

$$\{FR_n\} = \begin{bmatrix} rp_{11} & rp_{12} & ... & rp_{1n} \\ 0 & rp_{21} & ... & rp_{2n} \\ 0 & 0 & ... & ... \\ 0 & 0 & 0 & rp_{nn} \end{bmatrix} \begin{bmatrix} vr_{11} & vr_{12} & ... & vr_{1n} \\ 0 & vr_{21} & ... & vr_{2n} \\ 0 & 0 & ... & ... \\ 0 & 0 & 0 & vr_{nn} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ ... \\ DP_n \end{Bmatrix} \quad (5)$$

By this representation, we want to take in consideration, in an axiomatic approach, the results of our mathematical problem formulation and the implemented algorithm and the considerations risen from problem implementation in VR world.

This means that we have to know the result of our implemented mathematical formulation and virtual reality environment validation to be able to make decisions on facility layout design.

3.2 THE VIRTUAL REALITY SYSTEM

Virtual Reality is a rapid developed computer interface that strives to immerse the user completely [12]. In this virtual world, the vision of computer system which is capable of generating, in 3-D real scale, information about behaviour of a manufacturing system is called Virtual Manufacturing (VM). VM provides the manufacture, including the manufacturing process and layout analysis, in a computer screen projection.

When we want to estimate manufacturing systems and/or product features, useful step is to make-up and design and simulate and analyze and optimize, in an computer realized world, a truthful representation of reality. The virtual reality environment offers rapid, realistic and easy modifiable creation of the process production model.

Given to powerful of software and hardware system and technologies, design can be performed on an electric platform, or namely in virtual environment. Across a computer based representation a lot of layout models, different in quality and in contents of the information, can be realized. Besides, the facility layout design has a prominent effect on the performance of the whole manufacturing system.

To this end, it is important for the industries to apply new methods and tools of Information Technology (IT) in order to support fixed requirements. Actually, computer system endows valuable support, not only to layout generating solutions but also in layout analysis and elaboration and refining solution. The

accuracy of the information from the realized model is crucial for the quality of the results.

Looking at the history of CAD/CAE (Computer Aided Design and Computer Aided Engineering) techniques, the trend was been to leave down computational systems going to support creative work systems. In the 1970's CAD systems with 2D 3D graphics wireframe[3] appeared. In the last ten year period, every CAD/CAE system has been provided of a window/menu based interface with shaded 3D models representation and not-direct interactivity by mouse and keyboard. Nowadays, a **Virtual Reality (VR)** technology, marked by real-time simulation and interaction with a 3D virtual world, handles with a new quality of presentation and interaction. The *"new proposal"* has been to *"project"* the running real world in a *"non-real"* environment: **Virtual reality Environment (VE)** in order to underline and mitigate design, production and planning mistakes , to evaluate and avoid dangers in workstation and work lead [13], for ergonomic analysis and human factor [14], for layout studies optimizing and reducing floor place, etc…. [15].

A virtual environment consists of a digital model which contains all geometrical informations about the product: CAD and other modelling systems. It provides basic data description like geometry and colour. VR system makes information about dynamics behaviour (simulation), physical feels (softness and roughness), weight and functional features.

VR interfaces enables the user's imagination upon viewing and manipulating virtual model.

In order to realize virtual manipulation and interaction in virtual environment user needs advanced tools and interface like audio-visual sensors, tracking systems, haptic devices [16]. In the VE man is present and soaked in an artificial environment, designed by software systems which are skilled to produce through user/hardware interfaces the natural world conditions Hardware and software systems are copying in the artificial state visual, olfactory, auditory and tactile excitements, taking over trusts, gestures and forces feedback like in the natural way.

Our model makes use of powerful virtual reality system (HMD, tracking room and projecting video-screen and suitable hardware and software systems (Fig. 4)) to validate in a virtual reality environment each proposed facility layout solution.

Figure 4: *The fully immersive Virtual Reality environment (VE).*

At the present, the implementation of a VR system meets with different incoming walls. We need a suitable hardware and software system to render images. We have to provide a fitting stereoscopic visual interface and tracking system in order to minimize delay time between action and gesture's measurement etc….

---

[3] 3D visualization method where each body is represented by its profile.

Still, the **plant layout definition,** as the correct production implementation, is performed across a virtual environment approach (Fig. 5). In our virtual reality representation we realized the plant layout validation and we performed the mapping criteria between functional and physical domain (Fig. 7). The results, in terms of quality and productivity for the implemented instance, of our approach will be present in the next paragraph (section 4).
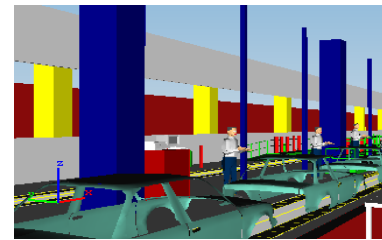

Figure 5:   Virtual factory side.

The virtual reality environment gave us the opportunity to perform by an expert analysis, in stereoscopic scale, the partial solutions of the fuzzy set optimizing procedure.

The outcomes of this approach have been used to link design fabrication shipping customer marketing requirements. VR can be a powerful tool for testing and evaluating new production ideas, reducing floor space and optimizing production (quality and time to market and cost are competitive points).

In our work, the design of the ending model is detailed through a sort of zigzagging between the Functional, Design and Process domain (Fig. 7). The mapping between the two domains is, cosily, realized across a suitable problem formulation, an appropriate solution procedure and a final virtual reality environment validation. In a full scale VE we realized ergonomic studies, we proposed and implemented production validation, we reduced the floor space, we improved the system and product quality, we simulated flow, we optimized production rate and workers saturation, we reduced cost, we balanced work's duties. In the virtual environment we performed ergonomic layout validation (Fig. 6) in workers' efforts, we tested the proposed layout solution in productivity and quality.
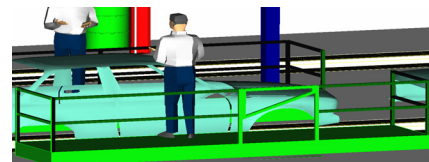

Figure 6:   Workplace and ergonomic validation in Virtual Environment (VE).

We used the results of the virtual validation to modify the proposed facility layout solution. Finally, the correlation between suitable mathematical problem formulation and virtual reality validation in a rational axiomatic design approach will give remarkable outcomes.

We are going to search for new efficient approaches to obtain robust placement alternatives. We got axiomatic design approach

and virtual reality environment implementation to assist us on
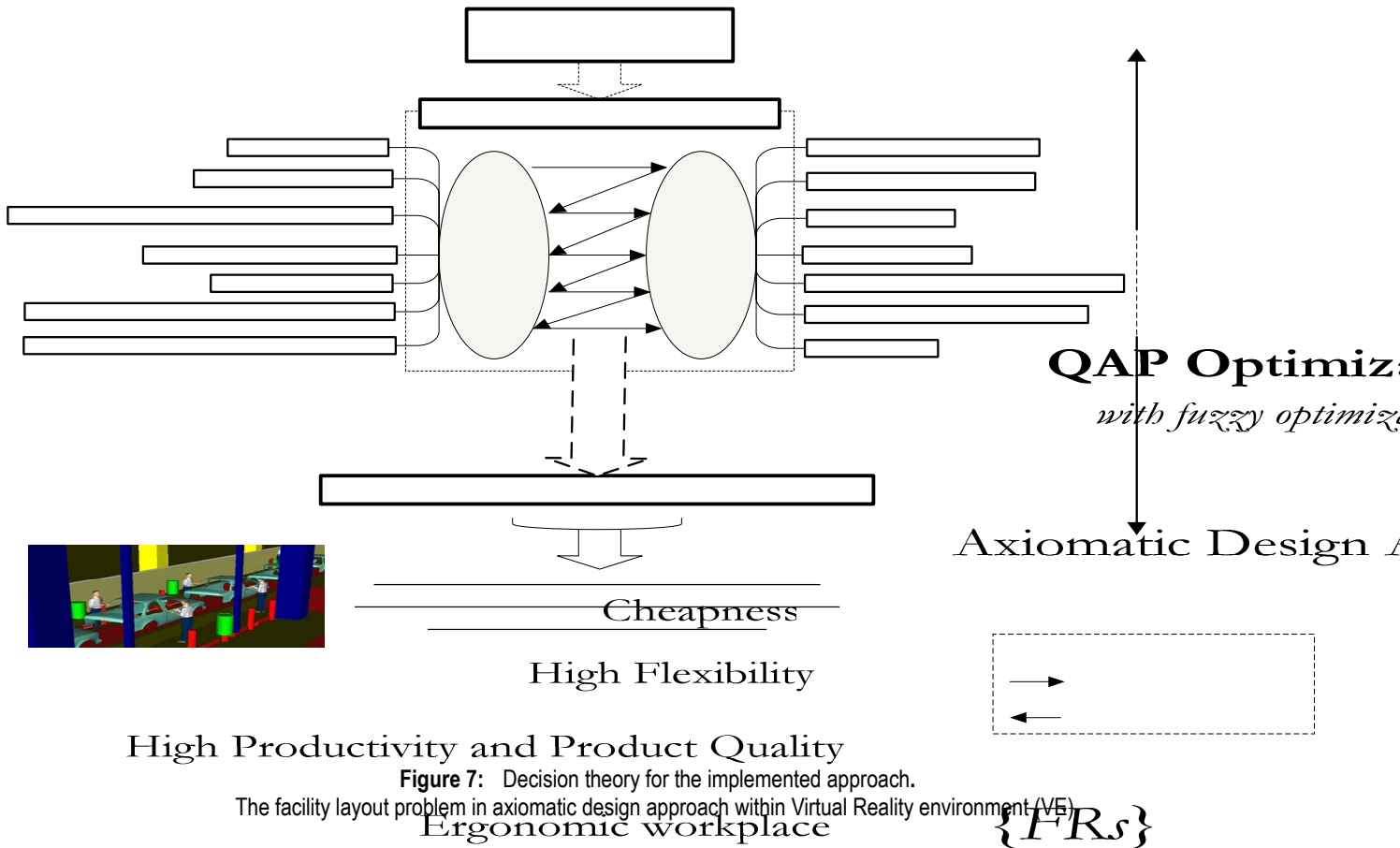
multi-objective problem.

Figure 7: Decision theory for the implemented approach.
The facility layout problem in axiomatic design approach within Virtual Reality environment (VE)

QAP Optimiz
with fuzzy optimiz

Axiomatic Design A

Cheapness

High Flexibility

High Productivity and Product Quality

Ergonomic workplace {*FRs*}

Setup reduction

Make easier the Production System

Flow, Resources, Space optimization

Functional Requirements
defined in functional
domain
WHAT?

Virtual Reality Environm

LAYOUT SOLUTION IN C
PRODUCTIVITY AND SAT
BALANCING OPTIM

4 THE RESULTS OF THE PROPOSED APPORACH IN A REAL MANUFACTURING SYSTEM

This section handles suddenly results for the implemented layout problem. We performed a real automotive facility layout problem. The problem is about a well automated automotive system that we more the one presented in this paper. We highlighted production inconsistencies. We increased productivity, quality. We reduced worker mistakes and floor space utilization. We removed product un-quality points. The points at issue are the obviously results that we will present in two concise tables (table 1-2).

The quadratic assignment problem formulation of the facility layout problem, performed the problem solution likely expert analysis implementation. The use of a rectangle packing placement algorithm with fuzzy set relationship gave us the possibility to have got and investigate one of the optimal layout solutions. The theory on the axiomatic design helped us to fit the optimal screening solution with a virtual reality validation.

In table 1 has showed a concise and clean prospectus about the production rates and the results of our implemented model. We realized a direct comparison between the existing solution, actually implemented in tested factory environment; we

implemented a general heuristic solution based on an expert analysis (we didn't presents the detailed saturation rates because in system caracterization we didn't suppose the detailed worker's tasks) and finally we implemented our procedure based on axiomatic design problem formulation within VR environment.

The results are obviously: VR in axiomatic design approach has been applied to solve a clients' real world layout problems and has increased worker rate, it has increase flexibility, it has reduced cost and locking up of capital.

The outcomes has been manifested in saturation rate (min and max and mean values have been highlighted) and in plant layout floor space.

The implemented procedures realizes, also, a worker reduction from 22 worker/shift[4] to 14 worker/shift (this is a certainly considerable cost's reduction) and a floor space with 55% reduction.

Another important aspect of our model is the result in relation to a general expert analysis. Across our axiomatic/virtual reality approach we performed better than heuristic procedures. We obtained a robust solution with reduction in space, workers and balancing tasks (table 1).

[4] The factory worked on shifts: it

Table 1: Summary for virtual reality benefits in our axiomatic design approach

		Existing plant configuration	A solution by a general expert analysis*		Our implemented approach by an Axiomatic/VR environment	
		Share	Share	Δ**	Share	Δ**
Max Saturation rate	[%]	87,01	—	—	80,86	-7%
Min Saturation rate	[%]	54,32	—	—	71,52	32%
Mean Saturation rate	[%]	69,27	—	—	74,15	7%
Workers/shift [unity/(8 hours)]		22	16	-27%	14	-36%
Plant layout	[m²]	528	416	-21%	236,8	-55%

* The solution has been implemented in term of production workers and workspace
** Δ= [Existing plant configuration - (Curret estimating solution)]

You will quite understand our waiting to publishing these results. The output in workspace and in balancing has been designed on a Cartesian plane (with saturation rate and performing task, namely UTE) to clearly present the gain in work space employment and in balancing work (Table 2).

Table 2: Balancing and work-floor reduction across the axiomatic approach implementation.

Δ= [Max share - Min share]

— Our implemented approach by Axiomatic/ VR environment

— Exsisting plant configuration
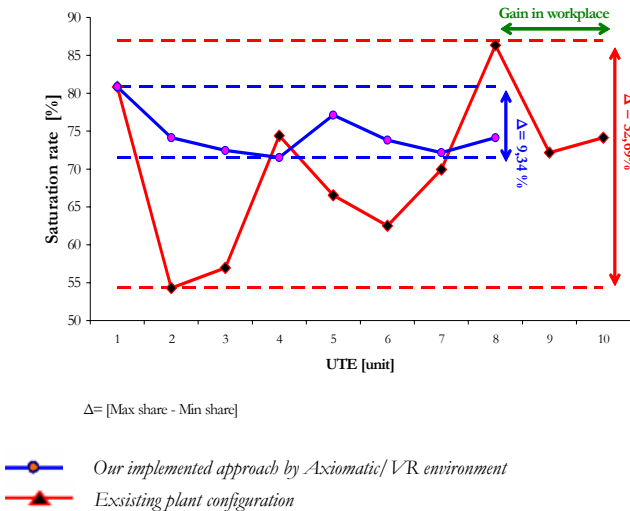
5 CONCLUSIONS

The facility layout design is a multi-objective problem. Recent results in the applications of powerful design system seem to indicate the Virtual Reality environment design can give rise to optimal configurations, in product and process. This study addresses the evaluation of FLD by developing an axiomatic approach in virtual environment, using a QAP formulation in layout generating solutions. The goal of this paper has been to present, full in detail and real factory implementation output, the power of virtual reality supporting by an axiomatic approach to the problem.

In this paper, it has been discussed how the Axiomatic Design can be used as the basis for establishing a systematic/robust facility layout design within virtual environment and for describing the design characteristic of manufacturing systems, machines of an important automotive factory. The spectrum of successful applications has been widened to include QAP

formulation of FLD problem. We have to introduce the QAP as a formulization of the problem and the RP placement algorithm as a building solution procedure based on fuzzy set theory.

Our methodology finds optimal solution for the implemented case.

To advanced the filed of manufacturing, further researches focus on more high-detailed designed solutions in virtual environment will be developed in our academic virtual reality laboratory during the next studies, focusing on ergonomic workspace analysis, virtual product and process prototyping and so on…

The emerging research indicates that considerable attention is likely to continue on this problem approach.

6 REFERENCES

[1] R. D. Meller and K. Y. Guan, 1996, The Facility Layout Problem: Recent and Emerging Trends and Perspectives, *Auburn University, Auburn, Alabama.*

[2] H. Murata, K. Fujiyoshi, s. Nakatake and Y. Kajitani, 1995, Rectangle-Packing-Based Module Placement, *IEEE.*

[3] N.P. Suh, 1998, Axiomatic Design: Advances and Applications, *Oxford University Press*

[4] M. R. Garey and D.S. Johnson, 1979, Computer Intractability: A guide to the Theory of NP-Completeness, New York WH Freeman and Co.

[5] P. Kouvlis, A. Kurawarwala, G. Gutierrez, 1992, Algorithms for robust single and multiple period layout planning for manufacturing systems, *EJOR.*

[6] G. Finke, R. E. Burkard and F. Rendl, 1987, Quadratic Assignment Problems, *Annals of Discrete Mathematics, 31.*

[7] T.C. Kopmans and M. J. Beckman, 1957, Assignment Problem and the Location of economics activities, *Econometrica, 25, 53-76.*

[8] M.R. Wilhelm, W. Karwowski, G. W. Evans, 1987, A fuzzy set approach to layout analysis, *IJPR, 25, 1431-1450.*

[9] J. Koopmans, M. Beckmann, 1967, Assignment problems and location of economic activities, *Econometrica 25.*

[10] N. P. Suh, 2001, Axiomatic Design, Advantages and Applications, *Oxford University Press.*

[11] D. S. Cochran and V. A. Reynal,1996, Axiomatic Design of Manufacturing Systems, The lean Aircraft Initiative, *Report Series.*

[12] T.S. Mujber, T. Szecsi, M.S. Hashmi, 2004, Virtual Reality application in manufacturing process simulation, *JMPT, 155-156.*

[13] Laurence E. Whitman, Michael Jorgensen, Kuresh Hathiyari, Don Malzan, 2004, "Virtual Reality: Its Usefulness for Ergonomic Analysis", *Winter Simulation Conference, 1740-1745.*

[14] M. Iqbal, M.S.J. Hashmi, 2001, "Design and analysis of Virtual Factory Layout", *JM PT, 118, 403-410.*

[15] F. Fruggiero, M. de Falco, A. and F. Lambiase, 2006, Trends and perspectives on Virtual Reality usefulness in manufacturing, *FAIM2006.*

[16] Dai and Gobel, 1994, "Virtual Prototyping – an Approach using VR-techniques", *In proceeding of the 14th ASME Int. CEC, Minneapolis, Minnesota.*