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# Workplace analysis and design using virtual reality techniques

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ABSTRACT

Workplace layout affects worker wellbeing and is linked to productivity, physical fatigue and production costs. So far, workplace optimization is based on observational methods and software simulations which may not be insightful, while full size prototypes signify high costs and implementation time. This work proposes a method to analyse and enhance industrial workplaces using immersive virtual reality. The system allows the tracking of multiple users virtually performing assembly tasks inside a CAVE system and the visualization of KPIs (e.g. completion time, traveled distance, ergonomics) for supporting decision making by production engineers. A case study is used to demonstrate the approach.



## 1. Introduction

The concept of Lean Manufacturing (LM) [1] is widely known to the industry and in combination with computer technology and automation, it has made significant impact on reducing the development time and the design and build cycles [2]. Simplifying workplaces is a core objective of LM as it affects the performance of manufacturing systems through the design of efficient layouts [3] which is the focus of this work. While a lot of research can be found in the literature [4–6], the methods used for layout planning in industrial settings are usually over simplified, neglecting constraints and actual human motion.

A variety of methods and tools can be utilized for supporting decision making during assembly workstation layout evaluation and (re)design. Value Stream Mapping (VSM) has been a strong method for lean thinking [7] and implementation in recent years. The Lean approach focuses on cost reduction by eliminating non-value adding activities [8]. Value Stream Analysis (VSA) [9] separates those actions that contribute to value creation from activities that create waste and identifies opportunities for improvement. A "Spaghetti Chart", also called "Physical Process Map", or "Work-flow Diagram" is a sidekick to VSM, as the later maps the conceptual route through a process while the Spaghetti Chart shows the actual physical one. It is a powerful mapping tool for improvement, with the ability to identify poor layouts and wasted motion in the VSA but is often neglected due to its simplicity. The Spaghetti Chart is used to analyze the distance covered, the going back and forth to a place and the wasted time in motion and/or transportation through the visual depiction of the physical flow of materials or human workers in a factory environment [10]. The purpose of this diagram is to identify potential problems such as long or confusing routes, loops and crossing paths. The benefits include the accurate analysis/optimization of the materials and people movements [11,12] as well as the identification of (a) inefficiencies in the factory layout, (b) opportunities for less handling, (c) feasible reallocation of resources for better utilization and (d) improvements in safety. Current practice is based on observation by following the operator and manually drawing arrows depicting the workflow. These may be used to optimize product/employee movement by revising the layout or processes to minimize unnecessary motion.

Virtual Reality (VR) has proven that it has real-world manufacturing potential and is nowadays being used in industries with many different functionalities such as training, decision support, product design [13] and review [14], helping with maintenance, simulation of industrial operations [15], etc. Recently, studies used simulations to enhance VSM analyzing data in a dynamic environment [16,17] and have even used VR to visually evaluate the characteristics of future setups [18,19]. Several research works have proposed creating non-immersive virtual worlds allowing both the simulation and the remote operation of actual processes [20], for process/product design and verification [21]. This configuration encumbers the various stakeholders of the workplace optimization to understand or handle complex data coming from the flow simulation.

Traditional technologies and decision support tools are not sufficient to deal with new challenges [22]. The main questions to be answered during an industrial layout evaluation and redesign, concern the location of the passive resources, such as working tables and fixtures, relevant to the humans' work path, focusing both on the efficient work flow of a single human as well as the implication of having multiple humans in the same physical space.

The proposed system design logic involves: (a) a human operator performing an industrial task inside a Virtual Environment (VE), (b) observation-based analysis of the task using a set of developed tools and data captured within the VE, (c) collaborative layout redesign and real-time evaluation of the alternative solutions, (d) online assessment of the design decisions that the engineer may consider providing a cost and time efficient, decision support system.

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The novelty of the approach lays in the integration of tools with different assessment functionalities that can be used online to acquire real time assessment of human actions.

This study is structured as follows: Section 2 describes the approach, detailing the functionality and benefits of its adoption; in Section 3 the implementation of the system is presented; in Section 4 a case study is used to demonstrate its application. Section 5 discusses the results and outlines future work.

## 2. Approach

The proposed method supports the rearrangement of the elements of a working space to reduce takt time, spatial footprint or manpower. The concept is to offer a VR based decision support tool for the evaluation and redesign of workplaces keeping human in the loop. The workflow of the method and the functionalities implemented in the system are shown in Fig. 1.

The discussed method supports the collaboration of different actors, namely engineers and operators, taking advantage of the benefits offered by a multi-user collaboration at the design process [23]. The actors collaborate in a controlled immersive environment, which eliminates the need for a costly 1:1 physical prototype. An important objective while redesigning a workplace is to minimize the total distance and thus the time that the worker travels between workstations/worktables. To capture this information, the process of drawing the Spaghetti Chart has been automated through the VR system and no longer performed by the engineer as occurs in the current practice. In this way the engineer can observe the workers without distraction and focus on how to efficiently capture their tacit knowledge.

In order to evaluate a layout, an operator is selected to perform the simulation of the task at hand by entering the virtual environment. The virtual setup is implemented as close as possible to the actual one, in terms of realistic representation and interactions. During the simulated task execution, optical tracking sensors collect spatial data and a task execution time benchmark is set. At the same time, the engineer is able to observe the simulation in order to detect problematic areas in the layout or the process. The system supports multiple operators, using a color coding to represent their individual trajectories and facilitate the review of the process. It also allows the synchronized review of tasks by different operators in the same space, by comparing time and spatial data to identify delays due to collisions. The Spaghetti Charts are superimposed and points of collision are highlighted in each Chart providing a clear image on the space that is utilized at the same time. The elimination of such instances helps to avoid confusion in cases where operators utilize resources in different time slots. The Spaghetti Chart has also been enriched with a heat map feature that visually indicates the amount of time workers spend on each area of their route. Thus, the engineer may detect bottlenecks that may require intervention. After the creation of the Spaghetti Chart, the goal is to simplify it, so that a less complex layout can be achieved. The engineer at this point has two options depending on whether he has already identified a problem: (a) either to modify the layout based on experience, expertise and visual feedback, or (b) rely on the automated layout planning tool that the system offers. In the first case, the engineer can intuitively re-arrange the elements of the workstation through either a visual interface allowing him to use the mouse for drag and drop actions or the immersive environment using hand tracking. The system provides on the fly feedback regarding the impact of the changes such as new estimates of the required distance and time to execute the task.

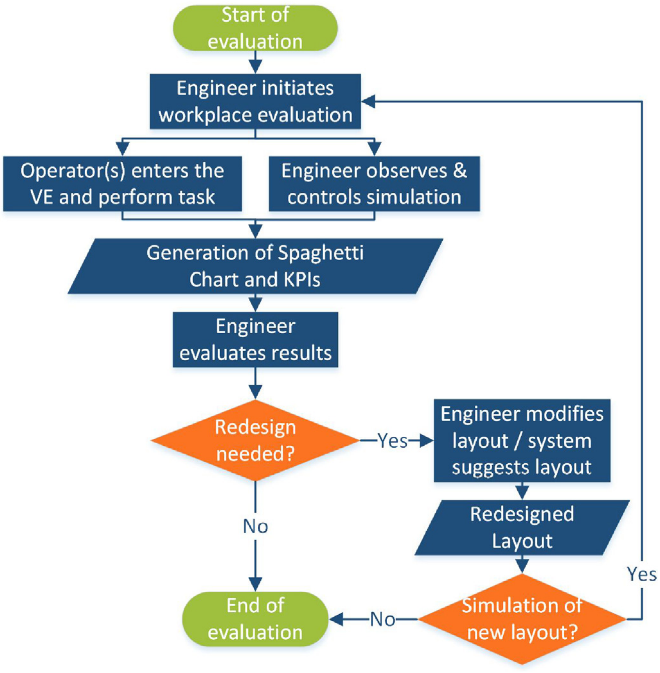


**Fig. 1.** Flowchart of the VR-based layout evaluation tool.

In the second case, the system may also propose a layout toward improving the current one. This function relies on the estimation of the total distance that the operator travels between worktables while he executes the task. Placeholders are defined to indicate areas where the layout elements can be positioned, and the system derives alternative layouts by creating combinations of assignments for the elements and placeholders. A path finding algorithm is used to calculate the operator's path for each alternative and sort them in ascending distance order.

The new layout can be validated by repeating the simulated task and iterations can be made until a satisfactory solution is reached. Tested layouts and simulation results, as well as the operator's data can be stored for offline review and analysis.

## 3. Implementation

### 3.1. System configuration

A 3-wall CAVE is used to provide a collaborative virtual environment. The CAVE includes three rear-projected walls using active stereoscopic projectors synchronized by three computers that form a cluster. In order to track the operator's movements, an optical motion tracking system is used, based on four VICON Bonita 3 IR cameras [24], each one placed at CAVE's top corners, combined with reflective markers. The reflective markers are placed on the operator's head and reflect the IR light emitted by the CAVE cameras, which is further analyzed to create a depth map for each camera. The aforementioned depth maps are fused, resulting in user's position data. Virtual-Reality Peripheral Network (VRPN) [25] is used to access this data through Unity3D [26] game engine at 200 Hz refresh rate. A pair of Wii Remotes [27] provide haptic feedback to the user offering a more realistic experience and precise grabbing/manipulation of virtual objects. In case the simulated scenario is executed by one operator, the system supports the utilization of Oculus Rift [28], a head mounded display which offers better immersive experience. Currently the deployment of posture capturing techniques, allowing high resolution real time tracking of human activities and direct calculation of ergonomic KPIs such as RULA [29], is an ongoing work. The integration of posture detection cameras in the described system configuration is also work in progress. An overview of the described system is shown in Fig. 2.

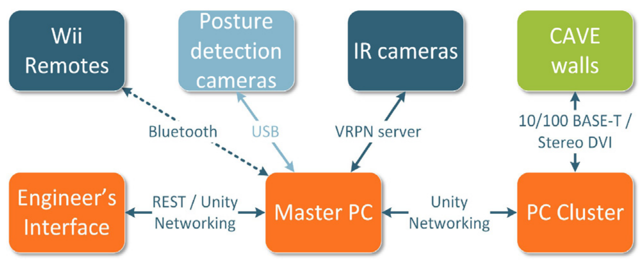


**Fig. 2.** System configuration overview.