Hybrid approach of discrete event simulation integrated with location search algorithm in a cells assignment problem: A case study

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Abstract

This paper describes a case study in an automobile assembly plant about a facility layout problem (FLP), where several cells have to be located in an industrial plant of reduced dimensions. The main objective was to support the decision-making process for managers. These cells are in charge of sorting and sequencing parts and components in trolleys to be delivered to the final assembly line. Each cell has an inbound and outbound logistic associated, which generates hundreds of material handling equipment (MHE) movements along the facility that have to be managed. Due to that, it is necessary to consider for layout designing at the same time not only physical constrains but also, traffic and safety issues associated to MHE. To that aim a hybrid optimization and discrete event simulation (DES) model is proposed. This approach allows us to reduce complexity by splitting designing into two phases. The first one simplifies the complexity as a typical combinational optimization problem, and uses local search heuristics to find near optimal locations. Then, a DES software is used to dynamically evaluate the layout alternatives and the whole logistics involved. This second phase provides a deep knowledge of the manufacturing system designed while considering not only quantitative, but also qualitative aspects related to traffic in-plant.

Keywords: Facility Layout Problem (FLP); Logistics; Traffic congestion; Discrete event simulation (DES); Automobile assembly line.

1. Introduction

The growth of global demand in the automotive industry has increased and as a result, the industry has become more flexible and responsive to market change (Jainury et al. , 2014). In addition, with the ongoing trend of mass-customization leading to an increasing product variety, a large quantity of parts or subassemblies have to be handled (Battini, Boysen, & Emde, 2013; Boysen, Emde, Hoeck, & Kauderer, 2015). Thus, not only production activities in the assembly line have to be considered, but also all the logistic activities besides production (Seebacher, Winkler, & Oberegger, 2015).

To ensure a continuous production flow, an uninterrupted supply of parts from the storage area to workstations is requested (Caputo, Pelagagge, & Salini, 2015). According to (Kang, 2001) there are over 20,000 parts or components in an average automobile, which, based on Battini, Boysen, & Emde (2013), cause more than 13,000 container deliveries per day from suppliers in a medium-sized automobile plant. Part logistics is increasingly becoming one of the greatest challenges in today's automobile production (Battini et al., 2013).

However, the logistic effort at the OEM can be further reduced if parts are delivered Just-in-Sequence (JIS). JIS means that parts are pre-sorted into bins by the supplier (Boysen et al., 2015). This sequence activity may be out of the facility due to the lean strategy of pushing the waste out of the line (Gould & Colwill, 2015) and carrying it to other facilities as well as the scarcity of space in the assembly plants.

Thus, assembly line supply needs to be considered carefully to enable satisfactory material flow (MF) control (Jainury et al., 2014). To that aim, material handling system (MHS) and facility layout play an important role in modern manufacturing companies (Gamberi, Manzini, & Regattieri, 2009). Iqbal and Hashmi (2001) defined layout design as the process that "involves the selection and arrangement of machines and material handling path and material handling devices". The layout design involves different aspects that must be considered at the same time such as constrains of costs, safety or availability (Tugnoli, Khan, Amyotte, & Cozzani, 2008).

In particular, the case study outlined below presents a facility layout problem (FLP) where several sequencing cells must be located in a new facility. These cells are in charge of sorting and sequencing parts and components in trolleys to be delivered to the final assembly line in a JIS manner. However, the main issue to tackle relates to safety regarding all the inbound and outbound logistic activities involved in the process that require thousands of forklift movements along the aisles. This handling equipment traffic must be considered during the layout design process.

The risk involved in the case study relates to two aspects. The first one concerns the coexistence of workers and vehicles in facilities. The second one, risks entailed during supply. High number of vehicle movements and operations in a limited area can originate traffic congestion or traffic jams during supply. Not only volume of movements but also mixed flow aisles (e.g workers, trolleys or Kanban routes), and other circumstances like the illumination or aisles width, may increase the possibility of these incidents. This situation could cause two consequences: loss of productivity in assembly lines and vehicle collisions.

Workflow congestion is a major concern in this kind of facility because it results in immediate safety problems in vehicles, and workers (Tompkins, White, Bozer, & Tanchoco, 2003). Zhang, Batta, & Nagi (2009) define congestion as a phenomenon that prevents vehicles from travelling freely and forces them to slow down or make a full stop. Kim, Yu, & Jang (2016) mention that some researchers find that the distance-based layout has poor performance due to congestion caused by blocking, traffic jams, and vehicle interference. More and more researchers consider MF congestion as a key aspect during layout design (see Benjaafar (2002); Gamberi et al. (2009); Kim et al. (2016) and Zhang et al. (2009). This paper considers traffic in-plant measures as traffic engineering. Then, traffic intensity refers to the number of vehicles crossing a layout's section during a lapse of time. Traffic congestion relates to traffic density, in other words, the number of vehicles being simultaneously in a given section of the layout, for example, an aisle. Both concepts are defined by the Highway Capacity Manual (HCM) (Board, 2010).

In addition, Leveson (2004) supported that new environmental changes such as the increasing complexity in systems or relationship between human and automation among others, request new accident prevention and risk assessment techniques. According to Centobelli, Cerchione, & Murino (2016), to make a well-designed layout and the manufacturing system more productive, the products have to move between the various areas in the simplest possible way, trying to minimize the material-handling flow, transportation distances, and movement of people within the facilities.

Due to the impossibility of eliminating the interaction of handling equipment and workers in the current facility, and physical facility constraints, we will look for alternatives that try to smoothen traffic by optimising the layout design using local search algorithm. Nevertheless, designing a complex manufacturing system required not only a static facility layout evaluation but also a dynamic knowledge of the system. To that aim, we propose to use Discrete Event Simulation (DES) modelling to evaluate the MHS, and the associated safety issues for each alternative. With the information provided by these tools we could help the decision-making process. These hybrid methods have been used before in assembly systems, as Prajapat & Tiwari (2017) introduced in their research paper, however, to our knowledge, combining optimization with DES has not been widely used to deal with FLP and logistics problems considering material handling equipment (MHE) traffic in manufacturing systems.

The rest of the paper is organized as follows. Section 2 introduces a brief literature review about different tools and approaches used in similar problems, introduces the case study and identifies the main issues involved. Section 3 presents the hybrid approach based on local search algorithms and DES. Section 4 outlines the real case study premises and numerical experiments. Section 5 summarizes the lesson learnt after the case study. Finally, the main conclusions and future research are proposed in section 6.

2. Literature review

Defining a manufacturing system disposal is known as the FLP which has been widely studied in the literature as a combinatorial optimization problem (Singh & Sharma, 2006). Krishnan et al. (2009) presented a FLP approach based on genetic algorithms (GA) that deals with the risk of the uncertainty of product demand during layout design. They classified the FLP into two types, static facility layout problem (SFLP) and dynamic facility layout problem (DFLP) assuming that in the last one the product demands vary from one period to the next. Ficko & Palcic (2013) designed a tool to generate robust layout designs for larger systems to help the decision-making processes. To that purpose, they used a specific heuristic known as the modified triangle method and GA for the FLP. Hasda, Bhattacharjya, & Bennis (2016) presented an algorithm based on a hybrid optimization method for solving either static or dynamic FLP with unequal size of compartments. Ku, Hu, & Wang (2011) proposed the implementation of Simulation Annealing (SA) and GA to address the FLP with unequal areas with a multi-objective function: MF cost, shape ratio and area utilization factors. Kulturel-Konak (2017) used a matheuristics approach to design unequal manufacturing and logistics facility. A Tabu Search (TS) determines the relative location of departments, while mathematical programming calculates their exact location and shape. More research works related to FLP using mathematical optimization can be found in Anjos & Vieira (2017).

Several research/researchers supported DES for addressing layout and MF problems. Iqbal and Hashmi (2001) supported that a 3D visual reality (VR) environment provides better understanding and brings to light potential problems such as safety issues, aisle and other layout problems. Moverover, Negahban y Smith (2014) supported DES as a helpful tool to show potential areas for improvement and make decision-making easier in manufacturing systems. They gathered several papers where DES is successfully applied in layout design and MHS problems.

Integrating optimization and simulation have been used in the literature before for different objectives. Zhuo, Chua Kim Huat, & Wee (2012) developed a hybrid method combining DES to evaluate an assembly system performance under different policies and enumeration-based search algorithm to optimise the available space. Their results showed that these hybrid models could significantly improve the performance of a dynamic space-constrained production system. Zhou, AbouRizk, & AL-Battaineh (2009) integrated DES for modelling space and logistics with genetic algorithms for optimizing the layout in a tunnel construction environment. This integration facilitated the necessity of dealing not only with parameters such as distance, material movements or safety conditions, but also the geometry of dozens of layout constraints. Kanduc & Rodic (2016) presented a novel heuristic method for layout optimisation, trying to reduce cost by minimising the total distance travelled. This method was validated using DES. Imran, Kang, Hae Lee, Zaib, & Aziz (2017) combined DES and GA to form an approach to minimize the work-in-process for cell layout problems in the automobile industry. Gamberi, Manzini, & Regattieri (2009) presented a model to obtain precise information of the MF involved in the production system, such as space requirements, transport requirements, performance indices, and time and cost of MF. To that aim, they integrate linear programming (LP), dispatching algorithm (da) and visual simulation (VS). Dehghanimohammadabadi & Keyser (2017) illustrated how linking the well-known SIMIO (DES software) with MATLAB, and object oriented numerical computation software, through the Application Programmer Interface (API) of SIMIO. They presented an Iterative Optimization-based Simulation model, and proposed a case study to demonstrate the flexibility of such hybridization scheme, which use three different algorithms (GA, SA and Particle Swarm Optimization (PSO)). Zupan, Herakovic, & Starbek (2016) studied the MF in a workshop type of production, and proposed a heuristic algorithm which aimed at simultaneously minimizing average flow time and orders' waiting times, and maximize average workstations' occupation. The algorithm encompassed several priority rules as well as a GA. Finally, a DES was developed to simulate and assess the MF produced by the afore mentioned methods.

As was proposed in previous research, integrating both tools provides several advantages, such as considering the dynamic aspects of production systems.
It also extends the functionality of the simulation tools, as well as being a promising avenue of research (Dehghanimohammadabadi & Keyser, 2017). Hence, in this work we propose to use both tools to support the decision-making process of the design of a production system. This process should consider not only an assignment problem but also an evaluation of the corresponding MF from the point of view of the safety of the traffic of forklifts, that will be evaluated not only quantitatively but also reviewing qualitative aspects.

3. Problem description

The case study of this research raises the necessity of supporting decision-making during the design of a new facility of a car assembly plant. The new design requires deciding the assignment of a number of sequencing cells along columns of cells. These sequencing cells are responsible for preparing preassemblies and placing them in trolleys of a certain capacity, following the sequence of the final assembly line. In addition, it is known that all the cells have the same width, and their length is variable. The cells have a picking area and a high-rise storage area. The cells belong to different suppliers, who have their own workers and forklift fleet. The workload in the plant is expected to be appropriated and it will not provoke any bottleneck during supply.

Figure 1 illustrates the layout of the described facility where j ∈ {1 ... Jmax} refers to the cells columns, k refers to the aisles between them, and I identifies the number of the cells assigned to a given position.

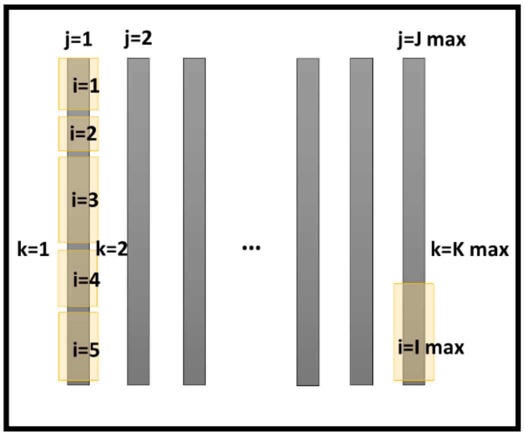


Figure 1 Layout simplification

On the other hand, all the inbound of pallets and the outbound of trolleys of each cell for an average production day is assumed to be known. The pallets arrive in trucks, and are unloaded one by one in docks by forklifts, which place them on a tow train of a certain capacity. Once filled, the tow train drives the pallets into the facility, where another fleet of forklifts is responsible for unloading the pallets one by one and taking them to their corresponding cell. Simultaneously, the outbound follows this process. When the cell operators fill the sequenced trolleys, the MHS receives a request and sends it to a driver, who will pick up the cart and tow it to its point of consumption on the final assembly line. The consumption points may be in different areas. Tow trucks can carry one or more trolleys simultaneously. Both supply processes in turn perform the reverse logistics, returning the sequenced trolley or empty pallet to the starting point. All this MF will generate hundreds of movements of MHE simultaneously in the same plant. The next subsection provides a math formulation to the static part of the problem described.

3.1 Mathematical formulation

The mathematical formulation represents the manufacturing facility described where /I/ sequencing cells have to be located along the /K/ cells columns available. The logistics involved have been simplified for the mathematical formulation in the following manner. The MHE movements generated in the aisles due to the daily inbound and outbound at a given cell column are supposed to be equally distributed between its two adjacent aisles. The mathematical formulation tries to minimize the total amount of movements generated in the aisle that has the highest traffic after an average day of production. Other logistics steps and dynamic aspects of the production system are overlooked at this stage but they will be dealt with as it will be explained. Doing so, we intend to balance the flow over the whole facility and minimize higher critical points in the layout.

3.1.1 Sets and indexes

i:	cells	i = 1 … I
j:	columns of cells	j = 1 … J
k:	aisles	k = 1 … K

3.1.2 Parameters

T_j	Column (j) length
S_i	Cell (i) length
M_i	Average number of movements originated by cell (i) during a production day

3.1.3 Decision variables

$x_{i,j} =$	1 if cell (i) is located in column (j) 0 if cell (i) is not located in column (j)
$Z_k =$	Number of handling equipment's movements generated in aisle (k) during a production day according to a given cell assignment.

3.1.4 Objective function (OF)

Objective function (OF1) aims to minimize the number of movements in the highest traffic aisle. Due to the existence of a large number of equivalent solutions and to break the symmetry in the solutions, a second OF has been proposed.

$$min\{max_1\ (z_k)\} \qquad \text{OF 1}$$

$$min\left\{max_1\ (z_k) + \frac{1}{2}\ max_2\ (z_k) + \frac{1}{3}\ max_3\ (z_k)\ + \frac{1}{4}\ max_4\ (z_k) + \frac{1}{5}\ max_5\ (z_k)\right\} \qquad \text{OF 2}$$

3.1.5 Constraints

This model includes three sets of constraint that consider the physical and logical aspects of the system.

$$\sum_{j}^{n} x_{i,j} = 1 \qquad \forall i \qquad (1)$$

$$\sum_{i}^{n} S_i \cdot x_{i,j} \leq T_j \qquad \forall j \qquad (2)$$

$$z_k = \left(\sum_{i}^{n} \frac{(M_i x_{i,j} + M_i x_{i,j+1})}{2} \right) \qquad \forall k \text{ Being k =j} \qquad (3)$$

Equation (1) assures that cell (i) is located at least in a column /j/, in one and only one. Equation (2) verifies that the cells assigned to each column /j/ do not exceed column´s length.

Equation (3) computes the number of movements per aisle /k/. As mentioned before it is assumed that the traffic generated by columns /j/ is split equally between its two adjacent aisles.

The formulation presented, is not able to effectively resolve instances of real size. In addition, to evaluate real production systems, it is advisable not only a global static view, but also dynamic. This is why the next section proposes a solving approach to this type of problem.

4. Solving the location problem

This section describes the approach followed to tackle the above problem. Our goal is to enhance MF safety in-plant by improving several KPIs related to material handling and traffic, including traffic volume, or daily movements per section or aisle. Although these "static" metrics that focus in average values over a leg or given period (movements per hour per section or aisle known as intensity) are the base for any layout design, dynamic values such as the maximum congestion observed during the rush hour, or the number of vehicles arriving to a given crossroad at the same time, are of the highest importance for a more robust design. Average and maximum number of vehicles observed in each aisle during a day, give a more detailed information about how the dynamic system would respond to the new performance of the facility. Moreover, a qualitative estimation will enrich the quantitative results when considering other restrictions such as aisle width desirable for a given traffic, or traffic management necessities to handle with a high volume of movements. However, these values cannot be estimated using static models but by means of dynamic approaches like simulation.

This is the reason why, like Dehghanimohammadabadi & Keyser (2017) and Zupan, Herakovic, & Starbek (2016), we elected to elaborate a two-stage approach to tackle the MF problem. The first stage named creating solutions, generates a feasible layout (e.g. locate the cells) that the total material handling movements along aisles by location cells is minimized in such a way. The second stage, logistics evaluation, takes the cells locations design produced at the previous stage and simulates the material and MHE flows in order to evaluate the dynamic performance of the design.

4.1 Creating solutions

The first stage of the model simplifies the problem described by considering only the static inbound and outbound movements in the adjacent aisles to cells. Given the number of possible combinations and the difficulty of considering all of the customer requirements in the mathematical model, it has been decided to decompose the problem. For instance, it should be appropriated not to share the same aisles by MHE from different suppliers. Thus, it is expected a greater simplification of the design alternatives, as well as a reduction in execution times. Once the feasible design solutions are obtained, they will try to improve through a local search heuristics.

4.1.1 *Construction algorithm*

The decomposition of the resolution algorithm used can be described as follows. On the one hand, it is desired to know the effect of separating the cells according to its destination point location. By doing so, the transport routes of the sequenced trolleys could be later improved. On the other hand, the cells belong to different suppliers that will work in the same workspace. To avoid possible lack of coordination when using different MHE fleets (each supplier has its own fleet), it is desired to separate cells according to their belonged suppliers. These two criteria present four possible alternatives: (1) not separating cells, (2) separating cells by supplier, (3) separating cells by destination, and (4) separating cells by supplier and destination. These alternatives in cases 2, 3 and 4 give rise to a decomposition of the problem into a series of sub problems that will be considered independent.

The proposed construction method works as follows. The cells are sorted into a vector according to a particular criterion "sorting criterion". Starting from the first cell, it is assigned to the column following the so called “assignment strategy” till all the cells have been successfully assigned.

Sorting criterion

Sorting 1	Cells are sorted randomly
Sorting 2	Cells are sorted from the greatest to the least number of movements
Sorting 3	Cells are sorted from the least to the greatest number of movements
Sorting 4	Cells are sorted from the longest to the shortest length
Sorting 5	Cells are sorted from the shortest to the longest

Assignment strategies

Assignment 1	The columns gradually fill up. The column k + 1 does not begin to be filled until the next cell of the vector to be placed does not fit into column k.
Assignment 2	A cell is placed in each of the columns alternating the order of these (k, k + 2, k + 4 ...). When it reaches k max, it returns to the beginning and fills the empty columns. Now each column has a single cell placed, the rest of the cells are located in the column with more available meters.
Assignment 3	A cell is placed in each column alternating the order (k, k + 2, k + 4 ...). When it reaches k max, it returns to the beginning and fills the empty columns. Now each column has a single cell placed, the rest of the cells are located in the column with less available meters.
Assignment 4	This approach seeks to balance the number of cells per column. Thus, the cells are placed according to the vector. It starts in column 1. In case that the cell to be placed does not fit in the assigned column, the columns are skipped to the next column. In the next filling round and starting from column one, it is desirable to fill the gaps from last round.
Assignment 5	This approach aims to place the most crowded aisles at the ends, where the aisles only feed a column of cells. For them the cells are placed alternating a column of the beginning with one of the end. For this, the cells are placed alternating a column of the beginning with one of the end (e.g. 1, k max, 3, k max -2, 5, k max -4 ...). When the algorithm reaches the central column, it proceeds in the same way, but this time from inner columns to outer columns.

To summarize, the algorithm chooses first the alternative. Then, a combination of sorting criterion and an assignment strategy is selected. Both options will be matched together to find the best design that minimizes OF1 for each alternative.

It is worth to mention that, it may happen that some of the combinations of sorting and assignment proposed do not allow to find a feasible solution, which in that case will not be considered. In addition, it is known that some of the combinations will not offer a solution that minimizes the OF1. However, to simplify the programming and being the next step improving the solution using local search, they are maintained. On the other hand, for that combination in which there is a random effect, it will be replicated N times to improve the robustness of the solution.

4.1.2 Local search

Once the solutions are obtained for all feasible combinations of each alternative, two local search heuristics will be applied. Both make small changes in the layout that seek to reduce the maximum amount of movement in the aisles.

The first heuristic involves exchanging cells to find solutions in a guided way with the aim of reducing OF 1. The process begins by selecting one of the cells located in the 2 adjacent columns to the aisles with the greatest number of movements. Then, the heuristic tries to swap each of the cells in those two columns, with the rest of the cells. When the heuristic finds a physically feasible exchange and it improves the OF 1, then the exchange takes place. This process is repeated again, going back to switch cells of the aisles with the greatest number of movements with those of the remaining cells of the layout. This process is repeated as long as exchanges are possible within the physical constraints and as long as the OF 1 continues improving.

The second heuristic consists on exchanging entire cell columns in an unguided way. From left to right, the heuristic tries to swap all the columns with each other. The first change that achieves reducing OF 1 will become valid and the heuristics will continue seeking new exchanges.

Both heuristics are applied individually and sequentially for each of the feasible solutions obtained from the first stage. Specifically, the heuristic loop will be repeated four times for each combination: apply heuristic 1; apply heuristic 2; apply heuristic 1 and then heuristic 2; apply heuristic 2 and then heuristic 1.

4.2 Logistics evaluation

Although mathematical optimisation can help to find good cells locations, it is important to consider the dynamic behaviour of the supply system as well as other factors like mixed production, drivers behaviour or environmental conditions such as aisles or entrance capacity among others, that should also be taken into consideration. To this end, we propose to combine optimization with DES, what refers to the second stage of this hybrid approach.

The best solution for each four design alternatives obtained by the optimisation process will be evaluated. Nevertheless, this time the whole logistics involved in the supply process and other dynamic aspects overlooked during the optimization process will be taken into account. By doing so, we will be able to estimate real-time traffic KPI values for every alternative.

The simulation model was designed based on the 4-layer approach (Saez-Mas, Garcia-Sabater, Morant-Llorca, & Garcia-Sabater, n.d.). This approach encompasses 4-layers or views: : network, layer, database and visual. Network covers all the paths and elements of the system. A logic layer works as an information system of the whole process. Database embraces input and output data needed to manage the simulation model. Finally, visual layer provides real aspect to the plant and facilitate the connection between the simulation model and final user. Several Andon elements can be used to highlight KPIs.

In addition, to enrich the evaluation, we proposed to check several qualitative features. To this end, we use a questionnaire, which evaluates some of the following aspects.

- Network design (e.g. number of lanes, one-way or two ways, crossing points or turns in the aisle).
- Management aspects (e.g. types of handling equipment at the same place, logistic activity or number of entrances).
- Environmental aspects (e.g. speed observed road signals, minimum aisle width, visibility or lighting).
- Material aspects (e.g. packaging size, stability or if the package rise above the MHE).

4.3 Pseudo code summary

The following pseudo code, represents the hybrid process used to find the most suitable layout configuration for the four desired alternatives. The pseudo code uses the following counters. Counter V indicates the number of combinations between cells sorting and assignments. Counter N tracks the number of generated random combinations and displays the quantity of replications for the same combination. Counter H identifies the combination of heuristics applied.

The simulation model was implemented in SIMIO, a DES commercial software. SIMIO API, the simulation model can be extended. The algorithms were programmed in C# and implemented in SIMIO.

Stage 1 – Creating solution

a. Select layout design criterion based on Alternative 1, 2, 3 or 4.
b. Set parameters, OF, variables and bounds. Initialize counters V, H and N.
c. Define an initial combination of cells sorting and assignment to create a solution. Increase counter V.
d. Generate solution N++
    - If the solution is unfeasible, skip the combination and try another combination in step C.
e. Apply the four heuristics to each solution. H++
    - If the solution if better than before, update OF1 and try another heuristics
    - If the cell sorting is random and N =200,000 go ahead the process; Else go back to step d to get more solutions.
    - If H = 4 go through the next step; Else go back to step e to apply other heuristic.

Stage 2 – Logistics Evaluations

a. Introduce the layout design to the simulation model.
b. Run the simulation model
c. Evaluate the logistics

5. Case study

The case study here presented is originated by a decision of the purchasing department of an automobile OEM factory. Two external suppliers supply more than 6,000 containers daily, using seven different facilities of more than 15,000 m2. They currently handle more than 2,200 references. Some of these facilities were located at least 500 metres away and in some cases more than 1 km away from the main OEM facility. Altogether, they had to deliver more than 10,000 sequenced trolleys. Trucks at best could hold no more than six units per trip. These make more than 3,500 kilometres of transport per day (see Figure2).

The rationale of the Purchasing department might be summarized as follows. By bringing the 70 sequencing cells inside the OEM facility, the number of travelled meters will be reduced and therefore the overall cost will fall. Moreover, they decided to perform all the activity in a facility with 5,000 square metres in the OEM Facilities that is underused. The new facility is in the field of an old plant, close to the factory that served for many years as the warehouse for the incoming material. The estimated savings represent around several hundred euros per year (see Figure 2).

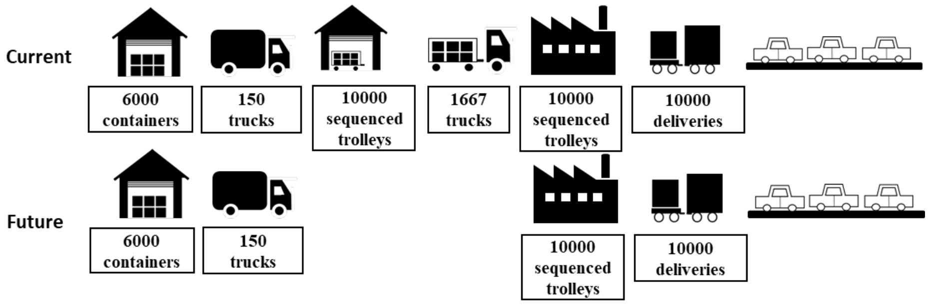


Figure 2 Sequenced parts supply stages and movements per day in current situation and in the desirable future

In terms of the layout, it is known that the facility has six docks to reuse for the new purpose. It also has 3 accesses to the assembly plant, 20 columns cells, and 21 aisles between cells. Each aisle has 65 meters length. Also in the upper side there is a main aisle for the inbound supply, and in the low side, there is another main aisle for the outbound supply to the assembly line.

The cells inbound process will be as follows. There is a specific time window for trucks arrivals. Unloading a full truck will take around 40 minutes according to plant estimations. The pallets are unloaded on a trailer station section (TS1) from trucks by forklifts four by four. Then pallets will be transported to a section located in the new facility, which is known as trailer station 2 (TS2) by towing trains in batches of 16 pallets per trip. Once in the facility, pallets have to be located in the associated cell by forklifts one by one. If a reference is exhausted in the cell, a forklift will go to lower a pallet from the high-rise warehouse, remove the empty pallet from the cell and fill the pallet's empty location. After that, the forklift will transport the empty pallet to complete the reverse logistics to the TS2. The outbound transport for sequenced trolleys is performed by tow truck that can tow 1-4 trolleys per trip. The same tow truck performs the reverse logistics. The Figure 3 represents all the steps and handling equipment involved in the supply process and implemented in the simulation model.

The allocated time for the total operation might be less than 45 minutes, of which transport might request more than 20 minutes. Therefore, trolleys usually cannot deliver more than 20-30 consecutive subassemblies together.

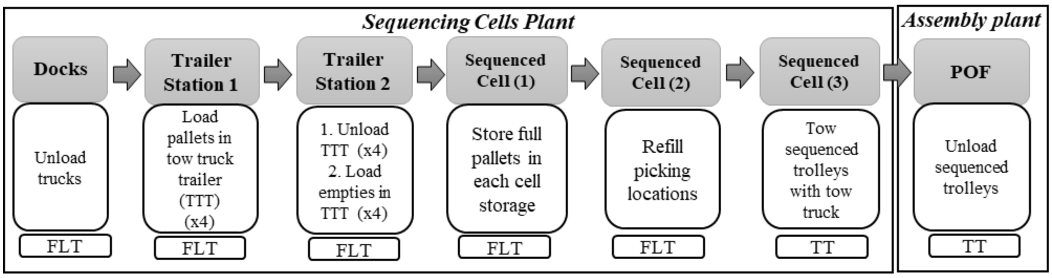


Figure 3 Sequencing parts supply stages.

The complexity of the internal logistics was not fully considered by the purchasing department during the decision-making process. The main concern was to tackle and help in decision-making process while redesigning the facilities layout and its new supply stages to sequencing cells. Due to the high volume of movements generated by this sequencing cells activity, layout design and handling equipment movements have to be properly evaluated to achieve the best possible solution.

5.1 Experiments

During the optimization stage, the total amount of combinations between cells sorting and assignment strategies, V, was set to 25. Each combination has been tested for each heuristics. For the random combinations, the model has been iterated 200,000 times.

The simulation model was used during the second stage to assess the four alternatives. Network layer holds all layout disposal such as cells, trailer stations, assembly line, material handling fleets, paths or aisles, crossing points or entrances. Each of the manufacturing system real elements necessary during the MF are implemented.

Besides that, in a separate layer we have added the simulation logic, which includes the information flow of the system. This layer includes the MHS, which manages all the logistic tasks such as unload trucks in docks, loop to supply pallets from docks and reverse, forklifts movements to transport pallets to each cell individually, and trolley deliveries from cells to the assembly line and reverse. The MHE serves the logistics tasks in a first in first out (FIFO) manner, and we enable the simulation software to decide the shortest path to run. In addition, the mixed-model assembly sequence is given by the logic layer using mix-model, daily production and several constraints. Operations in cells are not considered, and they are assumed as adequately estimated to avoid bottlenecks in the systems.

All the input data (e.g trucks time-windows, available fleet, inbound pallets, outbound trolleys etc.) is embedded in the database layer. In addition, simulation results and other support tables are also here located.

To easily detect how the handling equipment traffic affects to each area or aisle, we have implemented visual elements in the simulation model, referred to as Andon. The coloured icons represent the values of the different KPIs (see Figure 4). Arrows display the estimated traffic intensity. Intensity allows us to know the impact of production in specific plant sections, and the interaction of vehicles to identify critical points that experiment a high volume of movements. This information helps us to identify if current available network (entrances or aisles capacity) suit the new suppling necessities. In addition, bars display average and maximum congestion, and they help us to accept or reject proposals.

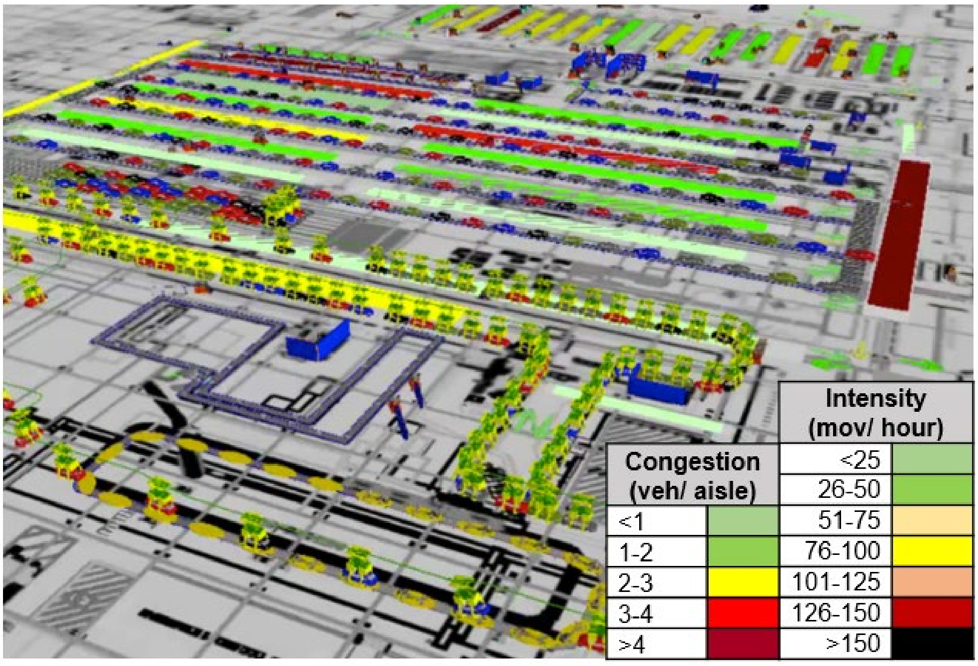
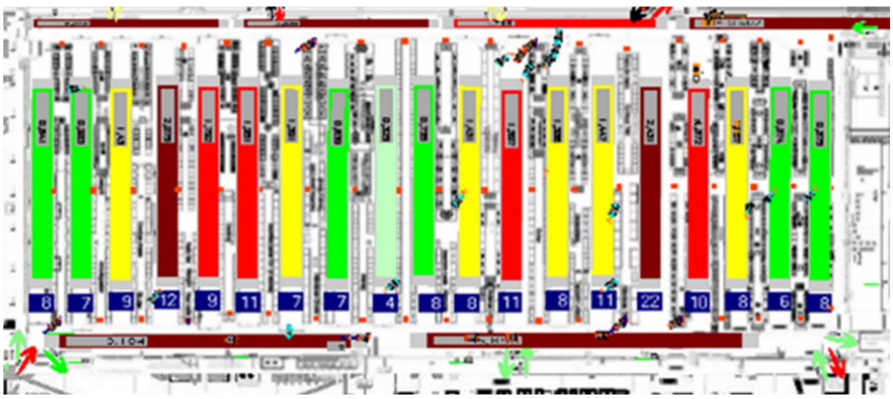


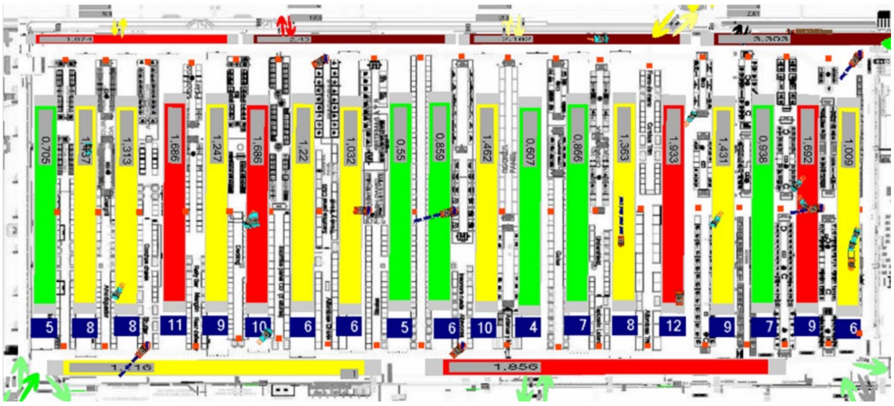
Figure 4 View of the simulation model of the new facility and the whole assembly plant with the Andon elements.

Figure 5 shows the simulation results for each of the four alternatives. These results were initially evaluated according to the client criteria, which mainly wanted to reduce congestion and to separate, as far as possible, the activity by destination and/or supplier.

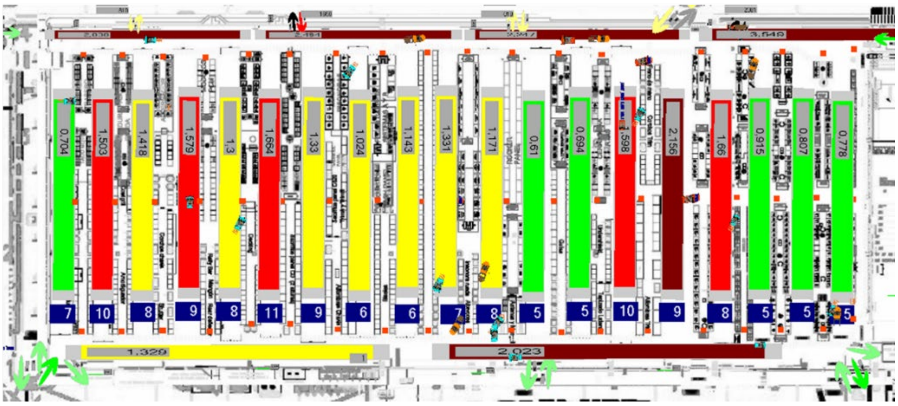
ALTERNATIVE 1



ALTERNATIVE 2



ALTERNATIVE 3



ALTERNATIVE 4

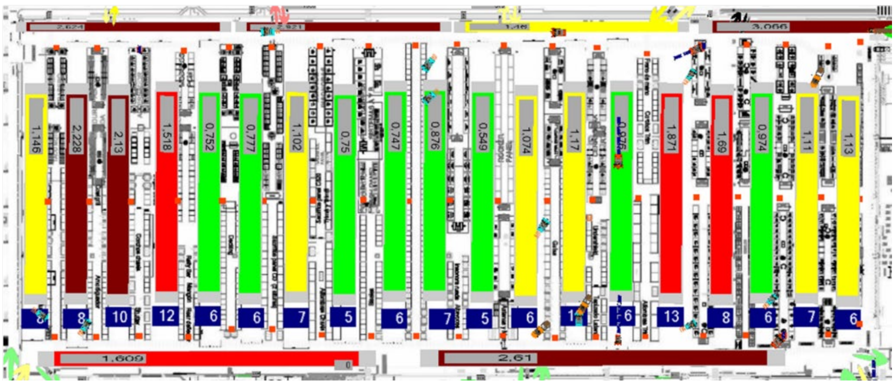


Figure 5 Andon Elements representing average congestion and the maximum number of moving trucks. Alternative 1: Results of the initial solutions. Alternative 2: Separating by suppliers. Alternative 3: Separating by destination. Alternative 4: Separating by suppliers and destination.

Alternative 1 was the first discarded, since it does not distinguish between zones by suppliers and destination. In addition, it shows a greater number of congested aisles than the other alternatives. This alternative registers a maximum of 22 vehicles simultaneously in one of the aisles. This situation is not feasible from a physical, operational and safety point of view.

Alternatives 4 and 2, although both meet one of the cell separation criteria respectively, were rejected because of the high levels of congestion in a greater number of aisles compared to alternative 3. Finally, it was decided to go ahead with alternative 3, which separates the cells by destination point and presents a smoother congestion along the aisles. From this alternative and knowing the traffic of the MHE associated, it was possible to evaluate in detail the selected design and to propose lines of improvement such as improving the route management initially proposed, as well as for the layout network.

For the last option, a questionnaire was used that considers qualitative aspects related to the MHE movements. This allowed us to advise the client on each critical point, what actions to implement to improve its management and avoid safety problems.

5.2 Lessons learned

The described case study raises not only a problem of cell location, but also the design of the involved logistics. The hybrid solving approach used has enabled us to reduce complexity by separating the design stage into two phases. The first stage simplifies the problem to a classic assignment one. In that stage, we consider the MF in a static way, which has helped us to know in detail each of the cells, the references that manages and their particularities.

The variety of initial solutions and the local search heuristics applied have allowed us to obtain a rich variety of solutions to analyze. However, not all the alternatives/sorting criterion/assignment strategy combinations produced interesting solutions, as illustrated by Figure 6. In fact, consecutively applying the local search with cell and column swapping does not represent a considerable improvement as shown. Applying the cell exchange already achieves, on average, a reduction of the maximum value recorded.

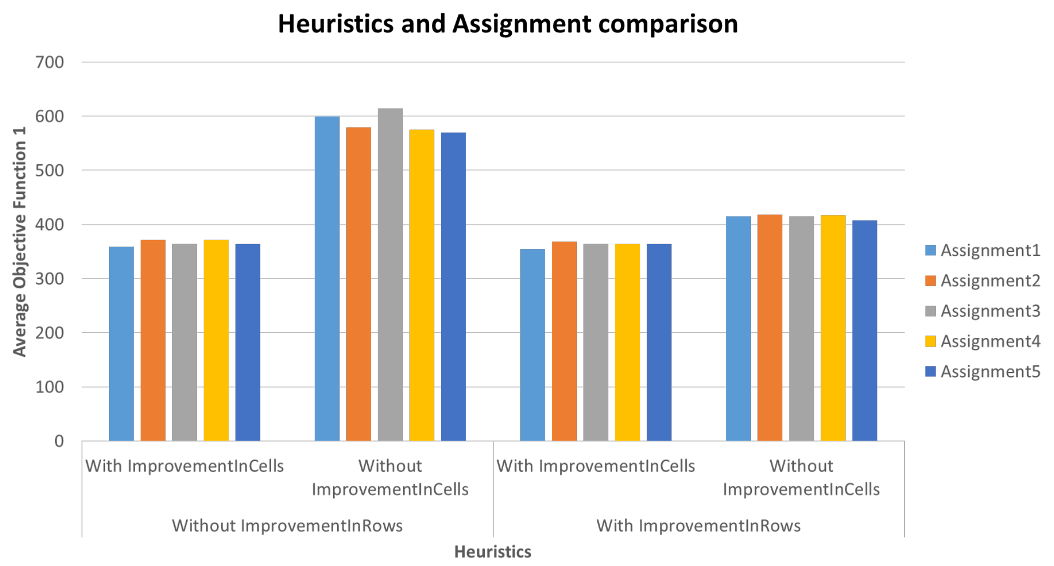


Figure 6 Comparison between average result of maximum after applying a heuristic improvement in cells, and after applying an iterative improvement in cells and columns.

During the second stage, it was necessary to build a simulation model to assess the 4 alternatives. On the one hand, to focus on the design of aisles and accesses of the plant, all of these elements have been simulated in the network layer. On the other hand, all the logic of the optimization model and the MHS has been modelled as another layer of the model using C #, thanks to the SIMIO API. This approach has facilitated the experimentation of the alternatives only by making changes in the parameters, without having to make changes in the programming code or in the layout. This modelling approach enables to create more realistic production systems, where the information flow is decoupled from the MF.

DES simulation verifies the dynamic effect of logistic operations on the layout alternatives. The simulation model has monitored the incoming traffic in the system. In addition, it provides a better understanding of the complete process, which helps to identify design inefficiencies not considered during the first phase. The simulation model has been validated with the static estimations.

The coloured visual elements have favoured the results understanding to the end user, in this case the client. Generally, the client is not familiar with the software interface, or is not able to visualize their problems in the manufacturing plant in a multiple results chart. Thus, representing the activity in the aisles with familiar measurable and ranges of colours, has allowed them to compare the future traffic situation, with the existing activity in other parts of the factory. This data exchange is considered one of the best lessons learned from the case study.

Thanks to the simulation results, the decision-making process could be supported. The simulation provides not only average estimations, that are relevant for engineers, but also the worst cases possible, which were part of the managers' interest.

Although the number of movements and traffic in some areas was unavoidable due to the daily demand, several improvements were proposed to manage and secure traffic in-plant. First, it was proposed to move those cells that generate a greater volume of movements to another plant area. In addition, traffic management measures were recommended, such as using light signals to identify busy aisles and preventing access of more MHE until the aisle is relieved. The same can be applied to crossing points between different aisles or accesses. It was also proposed to extend the case study to define unidirectional aisles to favour MHE flow.

However, it was also recommended to extend the length of the aisles. For this case some experiments were launched to verify what would happen by extending aisles 1 meter in length. Other solutions were obtained with better OF1 than currents. This option was not fully analyzed because it was out of scope and we had no evidence that it was feasible for the client.

6. Conclusion

This document presents a real case study related with the logistics supply to a mixed-model automobile assembly line. The case study presents a new facility design proposed by the purchasing department, in which the decision-making process overlooked the logistics involved. In particular, the case study presents an assignment problem in which 70 sequencing cells have to be located in a new facility. The main concern is safety in-plant, as the entire inbound and outbound logistics to cells generates hundreds of movements of MHE in the aisles.

The complexity of the logistics system requires not only a static evaluation of the future layout design but also to evaluate the dynamic behaviour of the system. To that aim, we propose a hybrid approach based on DES and a local search optimization. On the one hand, the optimization algorithm allows us to find a good cells assignment, which minimizes the maximum congestion of the aisles. In addition, the DES model provides relevant information for evaluating layout alternatives from a traffic safety point of view. The usage of coloured Andon elements for representing results favour the communication process with the client. Results highlight the unfeasibility of some of the alternatives from an operations and safety point of view, against the overview of the purchasing department.

Based on analysis of the results, it was recommended to move specific cells to another facility to reduce traffic and accident probabilities, and to implementing traffic management measures.

As future lines of research, we propose at least three open-ended questions to be asked. How to generate better solutions to this assignment problem to improve supply to assembly lines. How to assess safety in-plant associated with traffic congestion in a systematic way. Finally, to study the impact in the traffic in-plant of the network's typology of aisles and of the delivery route.

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