# Optimization of Production Planning in a Production Line Within an Automotive Company: Case Study

**Taraa Chaymae, Aman Zineb, Ezzine Latifa**
Research Team: Research and Development in Science and Engineering
ENSAM School, Moulay Ismail University
P.O. Box 15290, Al Mansour, Meknes 50000, Morocco
Taraa.chaymae@gmail.com latifae@yahoo.com, zineb.aman@gmail.com,

## Abstract
In order to improve the Supply Chain, satisfy the customer's expectations in terms of quality and deadlines, and improve the internal management of its resources, many manufacturing companies, works perpetually for the implementation of improvement and corrective actions to reduce quality defects and limit customer complaints. To ensure a good quality of the product, it is necessary to act on several parameters such as the diversity of the types of products produced on the same line and this, by elaborating an optimized planning of the production and by ensuring a sequencing of the references which maximizes the efficiency and minimizes quality defects. This paper, therefore, is concerned with the daily planning of production based on a mathematical model that minimizes the difference in product production times in order to maintain optimal speed of the line. As a result of this mathematical model, we get two decision variables: the quantity to be produced by each shift and the order of production per shift per reference, those results will help the planner to avoid shortage on the customer side and the producer to improve the KPIs related to the output quantity and the defaults percentage.

## Keywords:
Supply Chain Management (SCM), Modelisation, Optimization, Production planning and Cplex.

## 1. Introduction
In order to survive in an increasingly globalized and competitive marketplace, companies today must build, and rely upon continuous improvement on Supply Chain Management. Today, and more than ever, companies operating in the industry find themselves obliged to improve their industrial performance. It is in this perspective that the automotive industry strives to improve the quality of its product, its performance and its production system in order to better meet delivery deadlines, to adapt to its customer's demand and to achieve the desired pace.

It is within this context that this paper fits, with the theme of optimizing the daily production planning which aims to improve the quality of the product and the efficiency of the production line.
This present paper consists of three chapters. The first chapter is a literature review, the second chapter describes the production process and presents the problematic of the study case and the third chapter proposes a modeling of the problem followed by the preparation of the data and the resolution of the model.

### 1.1 Objectives
This present paper aims to improve the daily production plan taking into account the minimization of costs and the improvement of quality, production and logistics KPIs.

## 2. Literature Review
The operational management of most industrial processes has been thriving with the systematic improvement of production performance indicators to address the challenges of customer satisfaction, manufacturing/inventory/workforce liabilities, and delivery times. The complex dynamics of production

environments with uncertain demand and processing variability have been identified as a common problem in the development of efficient planning and scheduling tools, following the digital transformation of plants with advanced automation and data science applications Oesterreich and Teuteberg (2016). This paradigm is being continuously updated to consider the optimization of production layouts, human machine collaborations, or adaptive and flexible processes, among others. Despite the significant developments in optimization algorithms based on mathematical formulations, it is acknowledged the inherent computational limitations which hinder the requirement of a suitable shop-floor application for planning and scheduling. As Harjunkoski et al. (2014) reviewed the development of non-exact and decomposition-based approaches, advanced simulation models have enabled the evaluation of scenarios that mimic real operations and allow a better understanding of the complexity, explicitly measuring the impact of non-linear or stochastic behaviors Padhi & al. (2013); Frazzon & al.(2018);de Paula Ferreira, Armellini, and De Santa-Eulalia (2020).

To cope with these challenges, hybrid combinations among simulation models and mathematical optimization algorithms allow the establishment of different abstraction levels in each model to decrease the optimization complexity Figueira and Almada-Lobo (2014). While the simulation model can include a detailed online process representation, the adjustment of iterative parameters in the mathematical model allows an optimized solution convergence. This methodology is categorized as a Recursive Optimization-Simulation Approach (ROSA), which iteratively evaluates performance metrics of both models until a stopping criterion is met.

The main idea of Aggregate Production Planning (APP) is to translate forecasted sales demand and production capacity into future manufacturing plans for a family of products. The APP process is carried out at an aggregated level without the need to provide detailed material and capacity resource requirements for individual products and detailed schedules for facilities and personnel. Aggregation refers to the idea of focusing on overall capacity rather than the individual products or services. Aggregation can be done according to products, labour and time. APP greatly reduces the amount of data used during the planning process and therefore enables plans to be updated more frequently. Hence, changes occurring in factors such as demand, cost rates, capacity and material supply can be readily compensated for. In addition, when setting aggregate plans, it is possible to focus on those resources that limit production capacity that is bottlenecks.

Although the APP problem is a multiple-objective decision-making problem, the majority of the APP models are single objective. This is mainly due to the difficulty of solving multiple-objective decision-making problems. To overcome this difficulty in the majority of single-objective models, various cost objectives are combined into a single objective. The most commonly used APP objectives are minimize: cost, inventory levels, changes in work force levels, use of overtime, use of subcontracting, changes in production rates, number of machine set-ups, plant/personnel idle time; and maximize: profits, customer service. It is worth saying here that the preferable way of solving APP problems is to consider multiple objectives of concern simultaneously.

There are many APP techniques mentioned in the literature. Foote and Ravindran (1988) overviewed several APP models. Nam and Logendran (1992) gave a more recent survey of APP techniques. Several of these most frequently used techniques are as listed.

.a) Trial and error methods. b) Graphical techniques.c) Mathematical techniques:

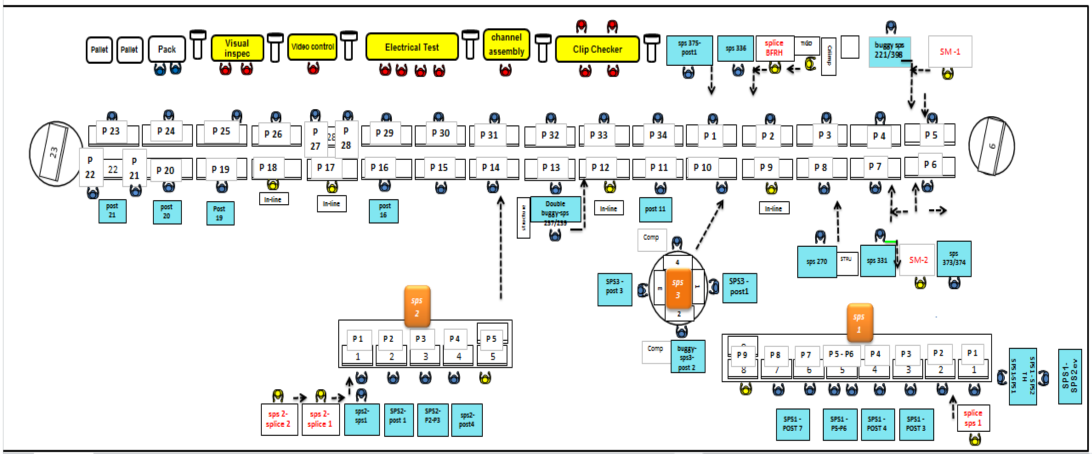
d) Linear decision rule. e) Search decision rule. f) Management's coefficients method.

g) Parametric production planning, h) Production switching heuristic, i) Linear programming.

j) Goal programming.k) Mixed integer programming. l) Transportation method. m) Simulation models.

Mathematical programming, and especially linear programming, is one of the best developed and most used branches of management science. It concerns the optimum allocation of limited resources among competing activities, under a set of constraints imposed by the nature of the problem being studied. These constraints could reflect financial, technological, marketing, organizational, or many other considerations. In broad terms, mathematical programming can be defined as a mathematical representation aimed at programming or planning the best possible allocation of scarce resources. When the mathematical representation uses linear functions exclusively, we have a linear-programming model.

The




classical linear programming models for planning production have been around for many years. A typical formulation of the LP planning model has the objective of minimizing the total production-related costs, such as variable production costs, inventory costs, and shortage costs, over the fixed planning horizon.

Figure 1. Line concept

The usual constraints employed are: (1) inventory balance equations for making the inventory and/or shortages balanced with those from the previous period, production quantity, and the demand quantity, (2) capacity constraints which ensure the total workload for each resource (labor, machine, etc.) not exceed the capacity in each period.

We consider the model problem min $\{c' x \mid Ax \leq b\}$ (1), where c and b are given n- and m-vectors, respectively, and A is a given (m, n) matrix. Thus n denotes the number of problem variables, m denotes the number of inequality constraints, and x is an n-vector whose optimal value is to be determined. We adopt the convention that all vectors are column vectors and transposition is denoted by a prime (e.g., x' and A'). Sometimes it is helpful to write (1) in the equivalent form: $\min \{c'x \mid a'_i x \leq b_i ,\ i = 1, \ldots, m\}$ .

Thus $b = [b_1\ b_2 \ldots b_m]$ and $A = [a'_1\ a'_2 \ldots a'_m]$, or $A' = [a_1, a_2, \ldots, a_m]$, where $a_1, a_2, \ldots, a_m$ are n-vectors. The ith constraint is $a'_i x \leq b_i$ and $a_i$ is the gradient of the ith constraint

Let R = { x | Ax ≤ b } . Here R is called the feasible region for (1) and c′ x is called the objective function. A point $x_0$ is feasible for (1) if $x_0 \in R$ and infeasible otherwise. Constraint i is inactive, active, or violated at $x_0$ according to whether $a'_i x_0 < b_i$, $a'_i x_0 = b_i$, or $a'_i x_0 > b_i$, respectively. $X_0$ is an optimal solution (or simply optimal) if $x_0 \in R$ and $c' x_0 \leq c' x$ for all $x \in R$.

## 3. Methods

To satisfy customer demand, the planner is required to plan the passage of several references (Part Number: PN) successively on the same production line.
Each PN requires a certain set up of the chain as the Man-hours (MHs) differ from wire harness to wire harness.
A MH is the sum of the times of all operations undergone by a Wire Harness (WH) to get it produced and ready for shipment.
Switching from one MH to another reduces the efficiency in terms of output (Quantity of produced wire harnesses) and affects the quality.
The problematic that arises is therefore: How to schedule and plan the sequence of PNs so that non-quality is reduced and efficiency is increased (reaching the planned quantity of production)

### 3.1 Description of assembly line

For the production of the main line of this project, we have 34 jigs boards, which is equivalent to 34 wire harnesses produced for each cycle of the chain. So each wire harness (jig) can be a different reference from the others as we can have the same reference occupying the whole line. It all depends on the customer demand for each reference as well as the planner's planning. The production is Just-In-Time
The jigs boards are with a layout (design) and holders to mount the components; each jig is used to mount a single wire harness per cycle of the chain.
The jigs are identical with the same layout which takes into account all the references of the line project. The work stations are balanced; each operator has the same duration of the tasks whatever the reference during production. The chain is rotatable; its speed is fixed for one cycle.

## 4. Data Collection

This present project is a diversified line, several references occurring on this chain, the difference in MH between these PNs creates quality anomalies and losses at the output level.

Quality defects can occur if we switch from a less loaded WH to another more loaded one without changing the set up (without slowing down) the speed of the line or if the chain contains both references at the same time and turns with the speed of the MH less loaded. The operator must therefore speed up his pace by mounting a loaded WH with a speed of a less loaded WH, which increases the probability of producing WH with anomalies.

For the output produced, when we have a loaded WH followed by another less loaded while maintaining the same chain speed or if we have both references at the same time, there is a risk of negatively impacting the quantity produced of the MH less loaded.

During our analysis of product defects, we extracted those which are due to the similarity between references. The table 1 summarizes our analysis, giving the types and number of defects caused by the similarity between references during the first 5 months of 2019.

Table 1. Defect types linked to similarity

| **Defect type** | **Quantity** | **Defect type** | **Quantity** |
|---|---|---|---|
| AA39 | 1 | AG26 | 1 |
| AA50 | 6 | AG39 | 2 |

| | | | |
|---|---|---|---|
| AB39 | 1 | AJ17 | 1 |
| AD26 | 1 | AK17 | 1 |
| AK26 | 7 | AW40 | 2876 |
| AW26 | 46 | AZ11 | 54 |
| **TOTAL DEFECTS :** | | **2997** | |

To analyze production data, we calculated the GAP from January 1 to the end of May 2019, i.e. the difference between the quantity actually produced and the quantity planned during the planning in the Master Production Plan. We found that there is a cumulative GAP of -258 WH, which is equivalent to a loss of 57.100 Euro due to the cost of overtime operators as well as the price of lost WH. The graph 2 shows the GAP MPS (Master Production Planning) for the first 5 months of 2019.

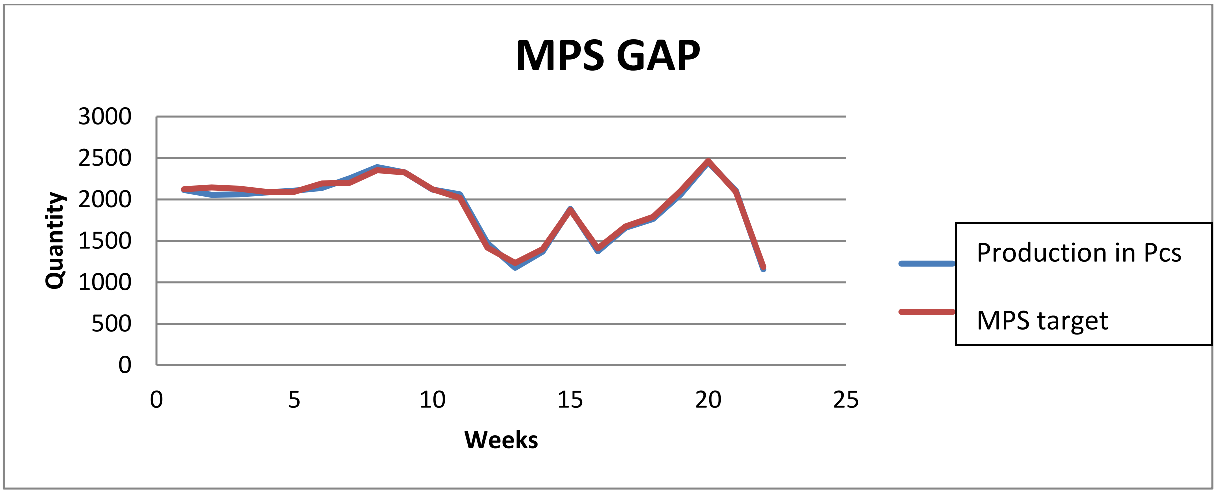



Figure 2 . MPS GAP

We integrated another notion at the model level, namely similarity and we based ourselves on the BOM (Bill Of Material) which is a file which presents the components of each WH and the design of each WH. Thus, to accentuate the quality aspect of the problem, the references which are similar to a certain degree must not follow one another so that the operator:

- make no mistake and place the same component on the same location for both references;

- do not put one branch of the WH in the place of another.

### 4.1 Model hypothesis

To build the mathematical model, we must base ourselves on a set of hypothesis and convert them into constraints in order to materialize all the aspects that we want to deal with.

The hypotheses of our model are:

- Approximately same quantity per shift in terms of parts;
- Same number of references (diversity) per shift approximately;
- Satisfaction of customer demand;
- scheduling of MHs;
- Assignment of references to shifts in a sinusoidal manner;
- Consideration of emergencies (customer fluctuation at the last minute).

- Consideration of the similarity of WH: if two references are similar in terms of components or design, they must be separated by another reference.

### 4.2 Model parameters

i, j: index of references.

n: total number of references varies between 1 and 61 in our example.

k: index of shift = 1, 2,3.

K: total number of shifts.

r: passage order of reference i.

Sij: difference in MH between references i and j.

EDI i: customer request for reference i.

CAPchain: line capacity.

dij: degree of similarity between references i and j expressed as a percentage.

s: similarity threshold.

m: minimum quantity to be produced from a reference.

### 4.3 Decision variables

$X_{ijkr}: \{1 \quad if\ the\ reference\ i\ in\ row\ r\ succeeds\ the\ reference\ j\ in\ the\ production\ of\ the\ shift\ k$

$$q_{ik}: the\ quantity\ to\ be\ produced\ of\ the\ reference\ i\ by\ the\ shift\ k$$

$$(1) \quad \min \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{K} \sum_{r=1}^{n} X_{ijkr} * s_{ij}$$

$$\{(2) \sum_{k=1}^{K} q_{ik} = EDI_i \quad \forall i \in \{1 \dots n\}$$

$$(3) \sum_{i=1}^{n} q_{ik} \leq CAP_{chain} \quad \forall k \in \{1 \dots K\}$$

$$(4) \quad -3 \leq \sum_{i=1}^{n} q_{ik} - \sum_{i=1}^{n} q_{ik'} \leq 3 \quad \forall k, k' \in \{1 \dots K\}, k \neq k'$$

$$(5) \quad -2 \leq \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{r=1}^{n} X_{ijkr} - \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{r=1}^{n} X_{ijk'r} \leq 2 \quad \forall k, k' \in \{1 \dots K\}$$

$$(6) \quad S_{ij} * X_{ijkr} \leq 0 \quad \forall i, j, r \in \{1 \dots n\}, k \text{ odd number}$$

$$(7) \quad S_{ji} * X_{ijkr} \leq 0 \quad \forall i, j, r \in \{1 \dots n\}, k \text{ even number}$$

$$(8) \quad d_{ij} * X_{ijkr} \leq s * X_{ijkr} \quad \forall i, j, r \in \{1 \dots n\}, \forall k \in \{1 \dots K\}$$

$$(9) \quad q_{ik} \geq m * X_{ijkr} \quad \forall i, j, r \in \{1 \dots n\}, \forall k \in \{1 \dots K\}$$

$$(10) \quad q_{jk} \geq m * X_{ijkr} \quad \forall i, j, r \in \{1 \dots n\}, \forall k \in \{1 \dots K\}$$

$$(11) \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ijk\,r+1} \leq \sum_{j=1}^{n} \sum_{j'=1}^{n} X_{jj'kr} \quad \forall r \in \{1 \dots n-1\}, \forall k \in \{1 \dots K\}$$

(1) Minimize the difference of MH of successive references for a shift so as to:
- guarantee the succession of references which have a close MH;
- optimize the setup of the chain.
(2) Satisfaction of customer demand.
(3) Line capacity.
(4) Same quantity to be produced per each shift, with a tolerance of ± 3 to avoid the impact of shift production indicators.
(5) Same number of references per shift, with tolerance of ± 2 to minimize diversity.
(6) and (7) Scheduling of MHs from min to max for odd shifts and from max to min for even shifts so that the chain set up is in sinusoidal form.

(8) Separation of similar WH of a degree s: if the degree dij of similarity of i and j is greater than the threshold s, i cannot succeed j, otherwise i and j can succeed each other.

(9) And (10) Relation between decision variables: if the references i and j are produced (Xijkr = 1), the quantities to be produced of i and j must be greater than the minimum quantity to be produced of these references.

(11) For a shift, if a row is not occupied then those following it are not also.

## 4.4 Data preparation

The present project is made up of 61 different references, each one characterized by its own MH.
We therefore took these references and we developed a matrix S of size 61*61, such that a cell Sij represents the subtraction of reference j MH from that of the reference i.
**$S_{ij} = MH_i - MH_j$.**
For the similarity matrix, we were based on:

1. BOM a file which contains the complete list of the components of each reference;
2. design (diagram) of references on jig;
3. The list of defects due to similarity.

We only took into consideration the most critical components that contribute the most in similarity defects, namely:

1. wires
2. connectors
3. clips
4. Tube
5. Fuses
6. Relays.

To build this matrix, we counted the similar components between references two by two, and then we divided by 663 which represent the total number of components.

### 4.5 Cplex software

IBM ILOG CPLEX Optimization Studio is a collection of tools for mathematical programming and constraint programming. It combines:
- an Integrated Development Environment (IDE) named Cplex Studio IDE (on Windows) or oplide (on Linux);
- a modeling language: the OPL language (Optimization Programming Language);
- two solvers: IBM ILOG CPLEX for mathematical programming (resolution of linear programs in fractional, mixed or integer numbers and quadratic programs) and IBM ILOG CP Optimizer for programming by constraints. By default, the CPLEX solver is activated.

The language used in Cplex Studio IDE is OPL (Optimization Programming Language). It is a modeling language that allows you to easily write linear (or quadratic) programs thanks to syntax close to mathematical formulation. In addition, OPL offers the user the possibility of separating the model from the data, so the same model can be easily tested with different datasets.

OPL works by projects: to solve a model the user must create an OPL project in Cplex Studio IDE which must contain at least a "model" file and a "runtime configuration" file. Indeed each project is made up of several types of files:

1. model file (.mod) which contains the model to be solved;
2. data file (optional) which contains the data for a model;
3. parameters file (.ops) (optional) which allows you to configure the CPLEX solver;
4. an execution configuration file (.oplproject) which tells the IDE what to do when the user requests the execution of the project, i.e. which model is to be solved and which are parameters and data.

The first step is to implement the model on Cplex, introducing the constraints, the objective function and the input data (the values of parameters).

The parameters to be entered are:

1. the minimum quantity to be produced (m);
2. the similarity threshold (s);
3. the number of references (nbRef);
4. the number of shifts (nbShift);
5. customer requests (EDI);
6. the similarity matrix (S);
7. the matrix of the differences of the MH (D).

We have introduced the values of m and s at the model level.

## 5. Results and Discussion

For this example, we have planned the passage of three references on two shifts. The MHs of its references are as follows:

Table 2 . MH of references

| Reference | MH (in hours) |
|---|---|
| Ref 1 | 5.29 |
| Ref 2 | 4.72 |
| Ref 3 | 4.81 |

The degrees of similarity between these references are grouped in table 3.

Table 3 . Similarity between references

| | Ref 1 | Ref 2 | Ref 3 |
|---|---|---|---|
| Ref 1 | 1 | 0.2 | 0.4 |
| Ref 2 | 0.2 | 1 | 0.6 |
| Ref 3 | 0.4 | 0.6 | 1 |

The minimum quantity to be produced for a reference is set at 2. The similarity threshold is set at 0.8. Customer requests for each reference are grouped in table 4.

Table 4. Customer demand (EDI)

| Reference | Customer demand |
|---|---|
| Ref 1 | 17 |
| Ref 2 | 40 |
| Ref 3 | 60 |

The results obtained are presented in table 5. Let's start with the distribution of quantities per shift:

Table 5. Quantities distribution per shift

| Reference | Shift 1 | Shift 2 |
|---|---|---|
| Ref 1 | 15 | 2 |
| Ref 2 | 38 | 2 |
| Ref 3 | 7 | 53 |

The shifts have the same number of references to produce. The quantity assigned to the first shift is 60 cables. The quantity assigned to the second shift is 57 cables.

The constraints of the shifts are therefore well respected (a margin of 3 WH).

The order of references for each shift is presented in table 6.

Table 6. references order in production per shift

| | | | |
|---|---|---|---|
| **Shift 1** | Ref 2 | Ref 3 | Ref 1 |
| **Shift 2** | Ref 2 | Ref 3 | Ref 1 |

To make the manipulation easier for the planner, we are working on a JAVA application that uses Cplex as a solver.This application has a graphical interface for entering data and must provide the results in the form of a table that is readable and understandable for the user.

## 6. Conclusion

This project is part of the process control and optimization production of automotive wire harnesses, with the objective of reducing the quality and meet customer requirements.
Taking into account the fluctuation and unstable demand of the customer, production scheduling and planning are required for both respond in time to customer requests and comply with all requirements in terms of product compliance and quality. Our project has thus worked to control the production planning and scheduling process.
The generated solution provides a sequencing of reference quantities to be produced by the different shifts in order to avoid problems of similarity and the variability of the MH relative to each reference.

## References

Vieira, M., Moniz, S., Gonçalves, B. S., Pinto-Varela, T., Barbosa-Póvoa, A. P., & Neto, P., A two-level optimization-simulation method for production planning and scheduling: the industrial case of a human– robot collaborative assembly line. *International Journal of Production Research*, vol. *60,no.9,* pp. 2942-2962, 2022.
Oesterreich, T. D., and F. Teuteberg., "Understanding the Implications of Digitization and Automation in the Context of Industry 4.0: A Triangulation Approach and Elements of a Research Agenda for the Construction Industry." Computers in Industry 83: 121–139, 2016.
Harjunkoski, I., C. T. Maravelias, P. Bongers, P. M. Castro, S. Engell, I. E. Grossmann, J. Hooker, C. Méndez, G. Sand, and J. Wassick., "Scope for Industrial Applications of Production Scheduling Models and Solution Methods." Computers & Chemical Engineering 62: 161–193, 2014.
Padhi, S. S., S. M. Wagner, T. T. Niranjan, and V. Aggarwal., "A Simulation-Based Methodology to Analyse Production Line Disruptions." International Journal of Production Research , vol. 51, no.6, pp. 1885–1897, 2013.
Frazzon, E. M., A. Albrecht, M. Pires, E. Israel, M. Kück, and M. Freitag., "Hybrid Approach for the Integrated Scheduling of Production and Transport Processes Along Supply Chains." International Journal of Production Research 56 (5): 2019–2035, 2018.
de Paula Ferreira, W., F. Armellini, and L. A. De SantaEulalia., "Simulation in Industry 4.0: A State-of-the-Art Review." Computers & Industrial Engineering 149: 106868. Figueira, G., and B. Almada-Lobo. 2014. "Hybrid Simulation–Optimization Methods: A Taxonomy and Discussion." Simulation Modelling Practice and Theory, vol. 46, pp. 118–134, 2020.
Baykasoglu, A. D. İ. L. (2001). MOAPPS 1.0: aggregate production planning using the multiple-objective tabu search. International Journal of Production Research, vol. 39, no.16, pp. 3685-3702, 2001.
Wu, N., & Coppins, R., Linear Programming. New York: McGraw-Hill, 1981.
Stockton, D. J., & Quinn, L., Aggregate production planning using genetic algorithms. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 209, no.3, pp. 201-209, 1995.
Mazzola, J. B., Neebe, A. W., & Rump, C. M., Multiproduct production planning in the presence of work-force learning. European Journal of Operational Research, vol. 106, no. (2-3), pp. 336-356, 1998.
Foote, B. L., Ravindran, A., & Lashine, S., Production planning & scheduling: Computational feasibility of multi-criteria models of production, planning and scheduling. Computers & Industrial Engineering, vol. 15, no. (1-4), pp. 129-138, 1988.
NAM, S. J. and LOGENDRAN, R., 1992, Aggregate production planning Ð a survey of models and methodologies. European Journal of Operational Research, 61, 1992.

NOOR I, H. and RADFORD, R., Production and Operations Management: Total Quality and Responsiveness (New York: McGraw-Hill).1995.
Stevenson, W. J., Production/Operations Management, New York; Richard D. Irwin, 1993.
Holt, C. C. (1960). Planning Production, Inventories, and Work Force.
Taubert, W. H., A search decision rule for the aggregate scheduling problem. Management Science, vol. 14, no.6, pp. B-343, 1968.
Bowman, E. H., Consistency and optimality in managerial decision making. Management Science, vol. 9, no.2, pp. 310-321, 1963.
Bensoussan, A., Crouhy, M., & Proth, J. M. (1983). Mathematical theory of production planning. North-Holland.
HWANG*, H., & Cha, C. N., An improved version of the production switching heuristic for the aggregate production planning problem. International journal of production research, vol. 33, no.9, pp. 2567-2577, 1995.
Johnson, L. A., & Montgomery, D. C. (1974). Operations research in production planning, scheduling, and inventory control. John Wiley & Sons Incorporated.

ELSAYED, E. A. and BOUCHER, T. O., Analysis and Control of Production Systems (Englewood Clis: Prentice Hall), 1985.
Özdamar, L., Bozyel, M. A., & Birbil, S. I. , A hierarchical decision support system for production planning (with case study). European Journal of Operational Research, vol. 104, no.3, pp. 403-422 , 1998.
Tabucanon, M. T., & Mukyangkoon, S. (1985). Multi-objective microcomputer-based interactive production planning. International journal of production research, vol. 23, no.5, pp. 1001-1023, 1985.
Bensoussan, A., Crouhy, M., & Proth, J. M. (1983). Mathematical theory of production planning. North-Holland.
Bowman, E. H., Production scheduling by the transportation method of linear programming. Operations Research, vol. 4, no.1, pp. 100-103, 1956.
Byrne, M. D., & Bakir, M. A., Production planning using a hybrid simulation–analytical approach. International Journal of Production Economics, vol. 59, no. (1-3), pp. 305-311, 1999.
Bakir, M. A. A hybrid analytic/simulation modelling approach to production planning (Doctoral dissertation, University of Nottingham).1996.
Mehta, P. (2004). Production planning and scheduling in multi-stage batch production environment (Doctoral dissertation, Thesis, Fellow Programme in Management", Indian Institute of Management, Ahmedabad).
Kim, B., & Kim, S., Extended model for a hybrid production planning approach. International Journal of Production Economics, vol. 73, no.2, pp. 165-173, 2001.
A.C. Hax, D. Candea, Production and Inventory Management, Prentice-Hall, Englewood, Cli!s, NJ, 1984.
P.J. Billington, J.O. McClain, L.J. Thomas, Mathematical programming approaches to capacity constrained MRP systems: Review, formulation and problem reduction, Management Science 29 (15) (1983).

## Biographies

**Chaymae TARAA** is an Operational Research Engineer. She received her Engineering Degree in Operational Research Engineering in 2019 from the INSEA School (National Institute of Statistic & Applied Economy). Her research interest includes modeling, optimization, supply chain management & continuous improvement.

**Zineb AMAN** is an Industrial Engineer. She received her Engineering Degree in Industrial Engineering in 2015 from the ENSAM School (EcoleNationaleSupérieured'Artset Métiers de Meknès). MoulayIsmaïl University,Morocco. Her research interest includes modeling and optimization, supply chain management.

**Latifa EZZINE** is a Professor at Department of Industrial Engineering, ENSAM School (Ecole Nationale Supérieure d'Arts et Métiers de Meknès), Moulay Ismaïl University, Morocco. She obtained her Ph.D. Degree in 2010 from the Faculty of Sciences, Moulay Ismaïl University, Morocco. Her current research focuses on statistics and artificial intelligence, modeling and optimization, control systems and telecommunications.