Cost optimal scheduling in an agro-food production workshop

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Abstract: This paper deals with an original application of the dynamic scheduling problem to a flexible manufacturing system of agro-food production. On the basis of an operations’ set, the objective is to find an optimal scheduling which minimizes jointly the cost of the out-of-date products and the cost of distribution discount, a heuristic based on the branch-and-bound method is used. Our goal is achieved while basing on coefficients indicating that the engagement of a production in favour of another is relatively urgent.

Keywords: dynamic scheduling, multi-objective optimization, dominance rules, minimization of the cost, branch-and-bound method.

1. INTRODUCTION

New applicability, like the flexible manufacturing systems or the parallel architectures (Carlier and al., 1988), returns the scheduling problems more complex what requires the rigorous resolution of these problems. The passage of a product’s type with another is generally done at cost’s price and tools adjustment’s time (Dusonchet and al., 2004). Thus, the evolution and the dynamic characteristics of the industrial workshops, in particular those of agro-food industries, impose the generation, in real time, of the scheduling process’ decision (Gargouri and al., 2003).

In general, the scheduling problems are multi-criterion optimization problems or multi-objectives (Gzara, 2001). Solving a problem of optimization consists in finding the best solutions checking a set of constraints and objectives defined by the user (Barichard and al., 2003). To determine if a solution is better than another, it is necessary that the problem introduces a comparison criterion. Thus, the best solution, also called optimal solution, is the solution leading to the best evaluation in comparison with the chosen criterion. In our work, we interested in the one-machine scheduling problem. In particular, we study the minimization criteria of the out-of-date products’ cost, and that of the discount of distribution; the optimal solution corresponds to that whose cost is minimal.

2. OPTIMIZATION PROBLEMS

2.1 Resolution methods’ classes

The optimization problems are in general difficult to solve. Several methods are used in order to find a satisfactory response to these problems. The exact methods and the approximate ones are distinguished (Barichard, 2003).

The exact methods examine, in an implicit way, the totality of the space of research and produce, in theory, an optimal solution. When the computing time necessary to reach this solution is excessive, the approximate methods can produce a quasi-optimal solution at the end of a reasonable computing time.

2.2 Multi-objectives optimization problems

The majority of the real optimization problems are described using several contradictory objectives or criteria to be optimized at the same time; they are known as multi-objectives problems. The sought optimal solution represents a set of points called «the face of Pareto », corresponding to the best possible compromise to solve this type of problem.

A multi-objectives optimization problem is formal-ized, generally, in the following manner:

\[
\begin{align*}
\text{minimizing} & \quad f(x) \ (k \text{ functions to be minimized}) \\
\text{such as} & \quad g(x) \leq 0 \quad (m \text{ constraints to be satisfied}) \\
\quad & \quad x \in R^k, \ f(x) : R^k \rightarrow R^k \text{ and } g(x) : R^m \rightarrow R^m
\end{align*}
\]

When \( k \) is equal to 1, the optimization problem is known as mono-objective.

To optimize a function of a given problem, it is necessary to determine the set of solutions. There exist two types of sets: the values’ set which can be taken by the variables, said search space, and the values’ set of the variables satisfying the constraints, known as realizable space.

2.3 Dominance concept

The optimal solution of the multi-objectives optimization problem, constituting a set of points, proves that is necessary to define an order relation between these elements known as a dominance relation, to identify the best compromises. The dominance rule is a constraint that can be added to the initial problem without changing the value of the optimum (Jouglet, 2002).

The most used is defined in the Pareto sense.

- Dominance (within the meaning of Pareto)
Definition 1
For a minimization problem and two vectors \( u \) and \( v \),
\( u \) dominate \( v \), \( u \preceq v \), if and only if \( f(u) < f(v) \)
\( u \) dominate slightly \( v \), \( u \P v \), if and only if \( f(u) \leq f(v) \)
\( u \) is incomparable with \( v \), \( u \not\preceq v \), if and only if \( f(u) \not\leq f(v) \).
- Global Optimality (in the Pareto sense)
- Local Optimality

Definition 2
A decision vector is known as overall optimal if and only if:
\( y \in \chi \) such as \( y < x \); \( \chi \) represents the set of the problem’s potential solutions; \( f(x) \) is called, in this case, effective solution.

- Local Optimality

Definition 3
A decision vector is known as locally optimal if and only if, for \( \delta > 0 \) fixed, \( y \in \chi \) such as:
\( f(y) \in \beta(f(x), \delta) \) and \( x < y \), where \( \beta(f(x), \delta) \) is a ball of centre \( f(x) \) and of radius \( \delta > 0 \).

#### 3. PROBLEMATIC

The problem is how to build a multi-criterion scheduling adapted to agro alimentary industries. Among the constraints and the criteria specific to agro-food industry, one can distinguish the out-of-date of the products and the discount of distribution.

The objective is then to select among the set of candidates operations the one which presents the best reducing compromise between the various criteria and by filtering the initial search space.

The decision to eliminate or to maintain an operation making it possible to avoid the time limitation of certain components, involves the costs’ reduction of these out-of-date components.

#### 4. THE OPERATIONS’ DOMINANCE’S RULES

**Notations**
- \( t_i^s \): effective starting time of operation \( O_i \) on post \( x \)
- \( r_i \): earliest starting time of the operation \( O_i \)
- \( \gamma_i \): effective completion time of the operation \( O_i \)
- \( P_i \): processing time of the operation \( O_i \)
- \( P_{rev} \): return delay of the product \( P_i \)
- \( c_{ik} \): cost price of the component \( c_{ik} \) of the product \( P_i \)
- \( P_{ren} \): unit selling price of the product \( P_i \)
- \( C_{ik} \): cost of storage per unit of time of a unit of the product \( P_i \)
- \( d_{rev} \): completion time of the sequence \( P \)
- \( DV_{rr} \): lifespan of the product \( P \)
- \( DR_{rr} \): delivery date of the product \( P_i \)
- \( d_{rev} \): delivery date of the product \( P_i \)

4.1. Problem formulation

Let \( E \) a set of \( n \) operations to be scheduled between two sequences \( P \) and \( A \) of already sequenced operations. For scheduling a couple of operations \( O_i \) and \( O_j \) of the set \( E \) of the candidates operations, the problem is to determine which of these operations is to be sequenced at first, i.e. the dominant operation, in order to minimize:
- the cost of the out-of-date products,
- the cost of the distribution discount.

So, it is able to filter the search space to build an optimal scheduling.

4.2. Branch-and-bound approach

The heuristic used is based on the branch-and-bound approach (Baptiste and al., 1996) (Bratcu and al., 1996) (Aggoun, 2004). It is one of the methods of constraints propagation to solve the problems of one-machine scheduling. It consists in using the initial constraints of the problem to develop and deduce new more strict constraints (Baptiste and al., 2001) (Le Pape, 1995): Detection of a situation to making a decision. This procedure is based on the technique of Edge Finding. It is a question of applying the technique of “branching” which consists in scheduling a set of operations which use the same machine. The “Bounding” makes it possible to deduce for some operations not belonging to the set \( E \) from the operations if they must, can or cannot be carried out before (or afterwards) the elements of \( E \).

These deductions make it possible to generate new relations of order and new bounds of time (Gargouri and al., 2003).

The branch-and-bound algorithm is carried out by dynamically building a search tree. The root of the tree is a node at level 1 indicating an initial scheduling \( S \). For this node there are as many nodes child of level 2 as the possible permutations to have corresponding schedulings. If the dominance relation is satisfied, search continues in this branch. On the other hand, if it is not satisfied, search is fallen through with this branch. In general, the dominance relations improve the efficiency of a branch-and-bound algorithm by constraining the search space (Allahverdi and al., 2005).
The proposed algorithm is applied to obtain an initial total cost (upper bound). During the branch-and-bound search, this upper bound is updated whenever a feasible scheduling is obtained which has a lower total cost. During the search, any incomplete branch which has a cost which is higher than the current upper limit is fathomed, i.e., this case is eliminated from the search space.

The proof of optimality is then performed “on the fly”, by dynamically reducing the cost after that the first optimal solution has been found and continuing the exploration of the same search tree (Caseau and al., 1995).

Algorithm

\textbf{Beginning}

\begin{align*}
  t, S = \{O_i, i = 1..n\}, O_i = \{e_i, p_i\}.
  \\
  1. \text{Initialization} \quad K(S), A = \{e_i, p_i\}.
  \\
  2. \text{while } j < k \text{ do}
  \\
  3. \text{For } i = 1..n \text{ do}
  \\
  4. \text{Permute } O_i \text{ to find } S_j.
  \\
  5. \text{Calculate } t_i \text{ et } C_i.
  \\
  6. \text{End of For}
  \\
  7. \text{Calculate } K_j(S).
  \\
  8. \text{If } K_j(S) < K(S) \text{ then}
  \\
  9. \quad S \leftarrow S_j.
  \\
  10. \text{Else } S \leftarrow S.
  \\
  11. \text{End of If}
  \\
  12. \quad j = j + 1
  \\
  13. \text{End of while}
\end{align*}

\textbf{End}

4.3. Formulation of the costs in the general case

In the general case, the cost of the out-of-date products \(k_1(s)\) and that of the distribution discount \(k_2(s)\) are written as following:

\begin{align*}
  K_1(s) &= \sum_i a_i \sum_j b_j \left( \max \left(0, t_i^* - a_i^* \right) \right) \left( \frac{e_i}{e_i^*} \right) \\
  K_2(s) &= \sum_i \alpha_i \left( \max \left(0, d_i^* - c_i \right) \right) \times \left( \frac{p_i - \left( d_i \right)}{D_i - D_i^*} \right) + e_i^* \tag{2}
\end{align*}

For the multi-objective evaluation, the objective function \(K_{\text{obj}}(s)\) is reduced to the minimization of the balanced sum of the criteria relating to the use of the aggregation operator OWA (Yager, 1988).

\begin{align*}
  K_{\text{obj}}(s) &= \sum_{i=1}^{n_c} K_i(s) 	ag{3}
\end{align*}

where \(n_c\) represented the number of criteria.

Remarks:

- The variables, for a scheduling \(s_i\) and a scheduling \(s_j\), are the effective starting time \(t_i\) and the completion time of the product \(C_i\).
- The coefficients \(a_i\) and \(b_i\) favour, from cost point of view, a product compared to another.

4.4 Exploration and study of the various cases of scheduling

To have an optimal scheduling, noted “\(S_{\text{opt}}\)”, which optimizes the quoted criteria, all these cases which can occur, in this part, are going to be studied then compared. Best scheduling is then going to be given in the sight of its exploitation. For two operations \(O_i\) and \(O_j\), the following cases are feasible

\begin{figure}[h]
  \centering
  \includegraphics[width=\textwidth]{fig1.png}
  \caption{Cases of scheduling}
\end{figure}

**Case1:** Scheduling \(S_1\) at an instant \(t\)

**Case2:** Scheduling \(S_2\), relating to the exchange between the operation \(O_i\) and the operation \(O_j\)

**Case3:** Scheduling \(S_3\), relating to the insertion of operation \(O_j\) just after the sequence \(P\)

**Case4:** Scheduling \(S_4\), relating to the permutation between the operation \(O_i\) and the operation \(O_j\) of case3

Remark: when the number of operations becomes significant, the cases of scheduling vary exponentially and the computation becomes complex.

4.4.1 Calculation of the costs for the various cases

* **Case1**

At a given instant \(t\), for the scheduling \(S_1\), where the sequences \(A\) and \(P\) are already scheduled; the cost of the out-of-date products \(k_1(s)\) is formulated by the expression (1), and the cost of the distribution discount \(k_2(s)\) is formulated by the expression (2).

* **Case2**

The exchange between operation \(O_i\) and operation \(O_j\), while keeping the sequence \(A\), leads to scheduling \(S_2\). In this case the dates of beginning and the end of the operations are updated as follow:
\( t_{s_i} \) : effective starting time of the operation \( O_i \)
\[
t_{s_i} = \max \left( d_{i-1}, r_i \right)
\]
\( \gamma_{s_i} \) : completion time of the operation \( O_i \)
\[
\gamma_{s_i} = \max \left( d_{i-1}, r_i \right) + p_i
\]
\( t'_{s_i} \) : effective starting time of sequence A,
\[
t'_{s_i} = \max \left( r_i, \gamma_{s_i} \right)
\]
\( \gamma_{s_i} \) : effective completion time of sequence A,
\[
\gamma_{s_i} = \max \left( r_i, \gamma_{s_i} \right) + p_i
\]

* Case 3
Insertion of operation \( O_i \) just after the sequence P, the scheduling \( S_3 \) is obtained and the dates are updated as follow:
\[
t'_{s_i} \) : effective starting time of the operation \( O_i \)
\[
t'_{s_i} = \max \left( d_{i-1}, r_i \right)
\]
\( \gamma_{s_i} \) : completion time of the operation \( O_i \)
\[
\gamma_{s_i} = \max \left( d_{i-1}, r_i \right) + p_i
\]
\( t'_{s_i} \) : effective starting time of operation \( O_i \),
\[
t'_{s_i} = \max \left( r_i, \gamma_{s_i} \right)
\]
\( \gamma_{s_i} \) : effective completion time of sequence A,
\[
\gamma_{s_i} = \max \left( r_i, \gamma_{s_i} \right) + p_i
\]

* Case 4
Insertion of operation \( O_i \) just after the operation \( O_i \), one will have the scheduling \( S_4 \) and the following dates:
\[
t'_{s_i} \) : effective starting time of the operation \( O_i \)
\[
t'_{s_i} = \max \left( d_{i-1}, r_i \right)
\]
\( \gamma_{s_i} \) : completion time of the operation \( O_i \)
\[
\gamma_{s_i} = \max \left( d_{i-1}, r_i \right) + p_i
\]
\( t'_{s_i} \) : effective starting time of operation \( O_i \),
\[
t'_{s_i} = \max \left( r_i, \gamma_{s_i} \right)
\]
\( \gamma_{s_i} \) : effective completion time of sequence A,
\[
\gamma_{s_i} = \max \left( r_i, \gamma_{s_i} \right) + p_i
\]

4.4.2 Example
Let us consider the following example:
- an operation \( O_1 \) is made up of two components \( c_{11} \) and \( c_{12} \) : \( O_1 = \{ c_{11}, c_{12} \} \);
- an operation \( O_2 \) is made up of three components \( c_{21} \), \( c_{22} \) et \( c_{23} \) : \( O_2 = \{ c_{21}, c_{22}, c_{23} \} \);
- an operation \( O_3 \) is made up of two components \( c_{31} \) and \( c_{32} \) : \( O_3 = \{ c_{31}, c_{32} \} \);
- the sequence A is made up of two operations \( O_4 \) and \( O_5 \), such as \( O_4 = \{ c_{41}, c_{42}, c_{43} \} \) and \( O_5 = \{ c_{51}, c_{52} \} \);
- \( \alpha_i = \beta_i = 1 \)

For this example, the cost of the out-of-date products is equal to:
\[
K(S) = \sum_{i=1}^{m} \frac{\max \left( 0, t_i - v_i \right)}{t_i - v_i}
\]
\[
+ \sum_{i=1}^{m} P_{i}^{w} \cdot \frac{\max \left( 0, t_i - v_i \right)}{t_i - v_i}
\]
\[
+ \sum_{i=1}^{m} P_{i}^{m} \cdot \frac{\max \left( 0, t_i - v_i \right)}{t_i - v_i}
\]
\[
+ \sum_{i=1}^{m} P_{i}^{w} \cdot \frac{\max \left( 0, t_i - v_i \right)}{t_i - v_i} \tag{4}
\]

The cost of the distribution discount is equal to:
\[
K_d(S) = \sum_{i=1}^{m} \max \left( 0, a_{i} - C_{i} \right) \cdot \left( \frac{P_{i}^{w}}{DV - DR_{i}} + C_{i}^{w} \right) \tag{5}
\]

The data relating to this example are defined in the table 1.

Table 1. The data relating to the example

<table>
<thead>
<tr>
<th>( O_1 )</th>
<th>( O_2 )</th>
<th>( O_3 )</th>
<th>( O_4 )</th>
<th>( O_5 )</th>
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<tr>
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<td>( r_2 )</td>
<td>( r_3 )</td>
<td>( r_4 )</td>
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<td>( P_{i}^{w} )</td>
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</table>

By application of our heuristics, the following experimental results are obtained, table 2. The unfeasible scheduling are eliminated.
The obtained results show a great disparity between the minimum cost and the maximum cost, this disparity is due mainly to the cost of the distribution discount taking into account its importance. It is noted that a good profit was obtained. This approach gives us the optimal solution, but, due to computation time the practical application is limited to small or medium size problems.

5. CONCLUSION

The approach developed in this work provides the possibility to determine an optimal scheduling among several realizable ones; this optimal solution generates the minimization of the cost of the out-of-date products and of the cost of the discount of distribution. Indeed, realizing rules of dominance of the operations and the parameters necessary for the calculation of the costs as well as the data of stock, we can avoid the lapsing of certain components. To achieve this goal, one maintains in the search space the operations whose components have the shortest validity limit dates. On the contrary, the operations of which the lifespan is sufficiently long and generating the manufacture delay of other operations are eliminated from the search space.

The disadvantage of this approach lies in the computation complexity when the number of operations becomes significant because the number of scheduling cases vary exponentially. To cure this difficulty, the future work is directed towards the application of the approximate methods such as genetic algorithms.

REFERENCES


Table 2. Experimental results

<table>
<thead>
<tr>
<th>Sequences</th>
<th>$K_1$</th>
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5. CONCLUSION

The approach developed in this work provides the possibility to determine an optimal scheduling among several realizable ones; this optimal solution generates the minimization of the cost of the out-of-date products and of the cost of the discount of distribution. Indeed, realizing rules of dominance of the operations and the parameters necessary for the calculation of the costs as well as the data of stock, we can avoid the lapsing of certain components. To achieve this goal, one maintains in the search space the operations whose components have the shortest validity limit dates. On the contrary, the operations of which the lifespan is sufficiently long and generating the manufacture delay of other operations are eliminated from the search space.

The disadvantage of this approach lies in the computation complexity when the number of operations becomes significant because the number of scheduling cases vary exponentially. To cure this difficulty, the future work is directed towards the application of the approximate methods such as genetic algorithms.

REFERENCES


Table 2. Experimental results

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