MILP Assignment Model for Labor Intensive Manufacturing Cells Considering Skills and Preferences

Irving A. Dávila, Viviana I. Cesaní
Department of Industrial Engineering
University of Puerto Rico at Mayagüez
Mayagüez, Puerto Rico, 00682, USA

Abstract

Operators in cellular manufacturing systems are an extremely important resource since they are the ones that drive the output by putting their effort directly into the manufactured product. An operator’s preference for a specific task has a significant influence in his/her performance due to its emotional impact. Operators with a high skill level in certain areas, but that prefer to work in other areas, can show some lack of interest, consequently lowering their performance. This work presents an assignment linear optimization model that considers both technical and non-technical characteristics of the operators, allowing them to be as satisfied as possible, while improving or maintaining the required cell productivity. A hypothetical case study was created in order to test the model functionalities, and proved to be a useful planning tool for management decision-making process.

Keywords
Cellular Manufacturing Systems, Labor Intensive, Mixed Integer Linear Programming, Labor Assignments

1. Introduction

While extensive research has been done in order to create better designs in cellular manufacturing systems (CMS), an important role in this area goes to the operators working on it. These are the ones that drive the output by putting their effort directly into the manufactured product. Factors as simple as mood, skills, and preferences, can highly affect the output in a production line. For example, most people would think that assigning the most skilled operator to a station would bring a higher productivity. This is not necessarily true; preferences may have a significant influence in an employee’s performance due to their emotional impact. An operator with a high skill level in a certain work area, but who prefers to be assigned to other areas can show some lack of interest, thus lowering his/her performance. Figure 1 illustrates a cellular manufacturing layout in which the number of processes required exceeds the number of operators available, thus requiring the ability of the operators to work on several machines.

![Figure 1. Cellular manufacturing layout](image-url)
The purpose of this work is to propose a method for improving or maintaining productivity in CMS, based on the operators’ technical and non-technical characteristics. This has been achieved by developing a model that assigns operators in labor intensive CMS, while taking into consideration their skills and preferences.

1.1 Problem Description

A variety of models have been created in order to assign operators to stations while maximizing or minimizing different metrics in CM environments. Some of these metrics are costs, operators’ skills, and productivity. However, operator’s preferences for a specific task have not been previously considered as an important characteristic of an operator’s performance when making assignments. Preferences, in the context of this work, represent a parameter that tells how interested an operator is in a specific area or task. On the other hand, skill is a parameter that refers to how skilled or productive an operator is in a specific area. The skill parameter is a measure that every company has to define in its own way. For example, for one company the skill of an operator could be defined as the amount of time the operator has been working the process, or the knowledge the operator has in the process. On the other hand, another company could define it as the productivity numbers related to the operator in the process.

The focus of this work is to take advantage of the nature of the CM environment, by creating an assignment linear optimization model that increases or maintains appropriate rates of production, while also allowing employees to be as satisfied as possible with their assignments. The model will assign the available operators to cell stations, while taking into consideration the characteristics of the cells, stations, and operators, in order to assure that the requirements of each cell and station are satisfied. Besides satisfying the requirements of the different cell stations, a preferences-skill combination metric of the operators is maximized to the greatest extent possible in order to assure that they will be working in the most comfortable and skilled manner. Figure 2 shows the system network of the problem being addressed in this work, where $s_{ijk}$, $p_{ijk}$, and $A_{ijk}$ represent the skill, preference, and assignment for each operator, cell, and station, which are represented by the indexes $i$, $j$, and $k$.

![Model’s system network representation](image)

Factors as bottleneck and non-bottleneck stations, assignments policies (intercell/intracell mobility), quantity of operators needed, operators’ skills, and operators’ preferences are taken into account in the development of the model, with the purpose of creating a model whose constraints represent to the greatest extent those found in real manufacturing environments.

With regards to bottleneck stations the model created will mainly consider the operator’s skill at the bottleneck station, thus having the most skilled operator assigned to the station in a dedicated way. In case there are various
operators with the same maximum skill in the bottleneck station, the model will assign between those the operator with the highest preference. Since employees can often be trained on multiple stations within a cell to allow for more flexibility and to account for employee absenteeism, it is assumed that the demand of operators needed in each cell will be less than the amount of stations in the cell. This means that operators are required to work among several stations in a cell in order to comply with the imposed cell demand, which makes our system a Dual Resource Constraint system (DRC). DRC systems are systems where the number of machines exceeds the number of workers, and both worker and machine capacity constrain the output of the system.

By using information about employee’s skills and preferences for each station, the model assigns the most skilled employees to the most important assignments (the bottlenecks), and the remaining assignments are based on the employees’ skill and preference combination related to the station. Since every assignment skill is maintained above a minimum skill required, it is guaranteed that production will be maintained at acceptable levels, and then enhanced with the high preferences obtained in the assignments. There are numerous reasons for a manufacturing plant wanting to maximize the job satisfaction of its employees. Obvious reasons include reducing employee turnover and absenteeism, and more importantly enhancing production, which are covered by taking into consideration employees’ preferences and skill levels as part of the assignment problem.

1.2 Literature Review

Within cell formation at the manufacturing environment Hoo and Moodie [1] and Liu et al. [2] proposed different solutions to this problem. Hoo and Moodie proposed a solution procedure for solving cell formation problems in flexible processing and routing manufacturing environments. They worked the case where a part does not have to follow a fixed path to visit some predetermined machines, and where operation or tasks can be performed in many different technical ways. Similarly Liu et al. proposed a cell formation algorithm that incorporates several key production factors, such as operation sequence, production volume, batch size, alternative process routings, cell size, number of cells, and the path coefficient of material flow, leaving behind once again the importance of the operator’s preferences in the process.

A hierarchical methodology for the design of manufacturing cells was proposed by Suresh and Slomp [3], which includes labor-grouping considerations in addition to part-machine grouping. The method synthesized the capabilities of neural network methods for rapid clustering of large part-machine data sets, with multi-objective optimization capabilities of mathematical programming. Süer and Sanchez-Bera [4] proposed a simultaneous solution of cell loading and cell size determination in labor intensive manufacturing cells. The study performed was a multi-period analysis where decisions were made for the next several periods. The objective was to maximize the number of products that can be completed with the available capacity in all of the periods considered with the distinctive characteristic that even though there are alternative cells where a product can be processed, once it is assigned to a cell, it is required that it is assigned to the same cell in the following periods as well.

Developing new methods for improving productivity, Kattan [5] presented an integrated approach to the design and scheduling of alternative hybrid multi-cell flexible manufacturing systems (MCFMSs). Kattan implemented branch and bound techniques to design group technology cells, followed by a balancing of the intercell workload of GT cells which led to a system with better utilization of the machines. Finally he proposed a heuristic method for the scheduling of a family of parts with the objective of minimizing the maximum completion time of each part.

Bokhorst and Slomp [6] studied the literature related to the design of labor assignment rules. They concluded that literature thus far has only paid limited attention to labor assignment in systems with worker differences, and more specifically, to the who-rule. With that in mind, a series of experiments were made by means of simulation. Two experiments were conducted to study the flow time effects of applying alternative who-rules, and three other simulation experiments were conducted to examine the flow time effects of the when-rule, the where-rule, and the who-rule in systems with limited labor flexibility with respect to the number of machines that workers can operate.

Kher and Fry [7] showed through design of experiments that the labor assignment policies selected have a significant effect on due date performance. Contrary to much of the literature on Dual Resource Constrained (DRC) systems, they showed that the choice of the where-rule seems to be more important to shop performance than the choice of the when-rule. Therefore, operations managers in shops manufacturing orders for both vital and non-vital customers should consider labor assignment policies and labor flexibility as important issues. McDonald et al. [8]
presented a model that assigns workers to tasks within a lean manufacturing cell while minimizing net present cost. In determining how to assign workers to tasks, the model addressed production requirements to meet customer demand, skill depth requirements for tasks, varying quality levels based on skill depth, and job rotation to retain skills for a cross-trained workforce. In selecting an appropriate labor allocation strategy, Cesaní and Steudel [9] proposed a framework to systematically compare different labor strategies based on a given number of operators. The framework consisted of a classification scheme and empirical measures, and simultaneously considered the concepts of workload sharing, workload balancing, and the presence of bottleneck operations. The experimental results suggested that the balance in the operators’ workload and the level and type of machine sharing are important concepts in determining the performance of cellular implementations.

At the Naval Surface Warfare Center (NWSF) DePuy et al. [10] discussed three heuristic approaches in order to assign tasks to workers based on skills requirements/competency profiles, and to generate a low cost training schedule to resolve current skills gaps. Although minimizing training costs is a very important objective for most companies out there, they stated that there are other factors that NSWC would like to consider as well. Such factors are taking into consideration worker preferences and manager preferences during the assignment process, thus showing us how the consideration of human issues in CM workers to task assignments is crucial.

Hyer and Brown [11] observed that engineers do not always appreciate being tied directly to the shop floor in manufacturing environments. They studied how a CM company provided an on-site tuition reimbursed MBA program, an in-house workout facility, onsite travel agency, and a 4.5 day work week benefits, all initiatives designed with the intention of engineers overcoming the resistance to the company’s policy of locating them on the shop floor adjacent to the cells they support. Relating to performance Fitzpatrick and Askin [12] presented a mathematical formulation of the team construction problem using a set of labor skill pools, and showed that team performance depends on individual behaviors and interpersonal interactions, as well as technical competence.

In an attempt to explore in more detail human issues in the CM environment, Bidanda et al. [13] presented an overview and evaluation of the diverse range of human issues involved in CM based on an extensive literature review. In addition to an extensive literature review in human issues, they made a survey to determine the importance of eight different human issues in CM and gave it to a sample of academics, managers, and workers involved in cellular design, leading to the conclusion that consideration of technical issues alone cannot guarantee that an organization can develop and implement an optimal cell design. The same reasoning was made by Nembhard and Norman [14] stating that human factors such as learning ability, motivational issues, and worker attitude, should be considered in order to make studies more applicable.

Through the literature review of this document it could be seen that there has been plenty of emphasis in the skills aspect of assignments, while on the other hand there is a lack of research with regards to considering the operators’ preferences when assigning them to tasks. With this in mind, a model for assigning operators to tasks was developed considering the operators’ skills and preferences in order to create an assignment that considers the human non technical characteristics.

2. Methodology
2.1 Model Stages
In order to achieve the model’s goal, three different stages were created, each one with a different objective function. The purpose of using three different objective functions is to be able to integrate different scenarios into the model. The first stage is used for the bottleneck stations’ assignments by mainly considering the operators’ skills. The second stage will maximize the minimum skill-satisfaction among all the operators, then this minimum operators’ satisfaction will be inputted as a minimum constraint in the third stage, with the goal of maximizing the total system skill-satisfaction. Figure 3 illustrates a flowchart of the model stages that are executed in the Lingo 11 programming. The flowchart shows the order in which the stages are executed, as well as the variables that are set to fixed values, in order to pass them from one stage to another.

![Figure 3. Model’s logic flowchart](image-url)
2.2 Model Assumptions
This section introduces the assumptions followed by the model in order for it to provide accurate results when implementing it at a manufacturing environment. The two main assumptions to follow are explained next:

1. Model parameters are known a priori based on company database. The following are the most important parameters that need to be considered.
   - Skill Levels – These are to be obtained through the cross-training matrix of the company.
   - Preferences – These are to be obtained directly from operators through focus groups and questionnaires made by the company.
   - Demand Requirements – These are to be obtained through the product mix and demand specifications of the company.

2. Cells and stations are located at near distances from each other. Since the model can assign operators to more than one cell and station, we need to assure that the distance between cell and stations is close enough for an operator to travel from one to another in a considerably short amount of time.

2.3 Mathematical Formulation
This section introduces the mathematical formulation of the model. The model is presented by sections, starting with the definition of sets, decision variables, parameters, objective functions, and finally the model constraints.

2.3.1 Sets
Operators \((i) = 1, 2… w\)
Cells \((j) = 1, 2… c\)
Stations \((k) = 1, 2… e_j\)

Where \(e_j = [e_1\ e_2\ ...\ e_j]\), represents a vector that provides the number of stations that each cell contains.

2.3.2 Decision Variables
Main Decision Variables
\(A_{ijk} = Assignment\ of\ operator\ i,\ at\ the\ station\ k\ contained\ in\ cell\ j.\)
\(BA_{ijk} = Bottleneck\ Assignment\ of\ operator\ i,\ at\ the\ station\ k\ contained\ in\ cell\ j.\)
\(U = Minimum\ operators'\ skill – satisfaction.\)

Auxiliary Decision Variables
\(Y_{ij} = \begin{cases} 1 & \text{if operator } i \text{ is allowed to be assigned at cell } j \\ 0 & \text{otherwise} \end{cases}\)
\(l_{ijk} = \begin{cases} 1 & \text{if there is an assignment of operator } i \text{ to station } k \text{ at cell } j \\ 0 & \text{otherwise} \end{cases}\)
\(NA_{ijk} = New\ Assignment\ of\ operator\ i,\ at\ the\ station\ k\ contained\ in\ cell\ j.\)

2.3.3 Parameters
\(M = Large\ constant,\ e.g.,\ 100000\)
\(w = Small\ constant,\ e.g.,\ .001\)
\(v = Maximum\ number\ of\ cells\ at\ which\ an\ operator\ can\ be\ assigned\)
\(h = Maximum\ number\ of\ stations\ at\ which\ an\ operator\ can\ be\ assigned\)
\(t_{ij} = \begin{cases} 1 & \text{if operator } i \text{ is trained to work in cell } j \\ 0 & \text{otherwise} \end{cases}\)
\(s_{ijk} = Skill\ of\ operator\ i\ at\ the\ station\ k\ contained\ in\ cell\ j\ (0 – 10)\)
\(p_{ijk} = Preference\ that\ operator\ i\ has\ for\ working\ at\ the\ station\ k\ contained\ in\ cell\ j\ (1 – 10)\)
\(d_{jk} = Time\ requirement\ in\ cell\ station\ j\ k\ (0 – 1)\)
\(r_j = Minimum\ Skill\ required\ to\ work\ at\ the\ station\ k\ inside\ cell\ j\ (1 – 10)\)
\(l_j = Minimum\ operator\ assignment\ permitted\ inside\ cell\ j\ (0 – 1)\)
2.3.4 Performance Metric
Skill-satisfaction is the main indicator used in our objective functions. It is a measure of skill fulfillment for an operator due to their assignment to a specific task. It takes into consideration the preference and skill of the operator in a station along with the amount of time the operator is assigned to the station. It is based on the concept that while more time you spend on a task that you like, the more satisfied you’ll be.

\[
b_{jk} = \begin{cases} 
1 & \text{if station } k \text{ at cell } j \text{ is a bottleneck station} \\
0 & \text{otherwise}
\end{cases}
\]

\[
\sum_{j=1}^{c} \sum_{k=1}^{e_j} p_{ijk} s_{ijk} A_{ijk} , \forall i
\]

2.3.5 Objective Functions
Stage 1 - Maximization of the Bottleneck Total System Skill

\[
\text{Max} \sum_{i=1}^{w} \sum_{j=1}^{c} \sum_{k=1}^{e_j} (s_{ijk} + w \cdot p_{ijk}) B A_{ijk}
\]

Stage 2 - Maximization of the Minimum Operators’ Skill-Satisfaction

\[
\text{Max} \left\{ \text{Min} \sum_{j=1}^{c} \sum_{k=1}^{e_j} p_{ijk} s_{ijk} A_{ijk}, \forall i \right\}
\]

\[
\sum_{j=1}^{c} \sum_{k=1}^{e_j} p_{ijk} s_{ijk} A_{ijk} \geq U, \forall i
\]

\[
\text{Max } U = \text{Max} \left\{ \text{Min} \sum_{j=1}^{c} \sum_{k=1}^{e_j} p_{ijk} s_{ijk} A_{ijk}, \forall i \right\}
\]

Stage 3 - Maximization of the Total System Skill-Satisfaction

\[
\text{Max} \sum_{i=1}^{w} \sum_{j=1}^{c} \sum_{k=1}^{e_j} p_{ijk} s_{ijk} A_{ijk}
\]

2.3.6 Constraints

\[
\sum_{i=1}^{w} A_{ijk} = d_{jk}, \forall j, k
\]

\[
l_{ijk} \in \{1,0\}, \forall i, j, k
\]

\[
l_{ijk} \geq A_{ijk}, \forall i, j, k
\]

\[
A_{ijk} \geq l_{j} \cdot l_{ijk}, \forall i, j, k
\]

\[
s_{ijk} \geq r_{ijk} \cdot l_{ijk}, \forall i, j, k
\]

\[
A_{ijk} \leq t_{ij}, \forall i, j, k
\]

\[
\sum_{j=1}^{c} \sum_{k=1}^{e_j} A_{ijk} \leq 1, \forall i
\]

\[
A_{ijk} \geq 0, \forall i, j, k
\]

\[
Y_{ij} \in \{1,0\}, \forall i, j
\]
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\[ \sum_{j=1}^{c} Y_{ij} \leq v, \forall i \]  
(16)

\[ \sum_{k=1}^{e_j} A_{ijk} \leq Y_{ij}, \forall i, j \]  
(17)

\[ \sum_{j=1}^{c} \sum_{k=1}^{e_j} l_{ijk} \leq h, \forall i \]  
(18)

\[ \sum_{i=1}^{w} BA_{ijk} = b_{jk} \cdot d_{jk}, \forall j, k \]  
(19)

\[ \sum_{i=1}^{w} l_{ijk} = b_{jk}, \forall j, k \]  
(20)

\[ \sum_{j=1}^{c} \sum_{k=1}^{e_j} l_{ijk} \leq 1, \forall i \]  
(21)

\[ A_{ijk} = BA_{ijk} + NA_{ijk}, \forall i, j, k \]  
(22)

Constraint (7) ensures that operators are assigned the right amount of time at each cell station. Constraints (8)-(10) work as an assignment binary control flag, where \( l_{ijk} \) will become one, only when \( A_{ijk} \) is greater than zero. Constraint (10) by itself works as a minimum possible assignment permitted by cell. Constraint (11) states a minimum skill required to be assigned at a specific cell station. Constraint (12) forces an operator to have cell training in order to work in a cell. Constraint (13) states that no operator can be assigned more than one work shift. Constraint (14) declares non negative assignments. Constraints (15)-(17) makes it possible to specify if the model follows an intercell or intracell assignment policy, which is done by setting the variable \( v \) that represents the maximum number of cells that an operator can be assigned to. Constraint (18) makes it possible to specify a maximum number of stations that an operator can be assigned to, which is represented by the variable \( h \). Constraints (19)-(22) are used for the bottleneck assignments model. Constraint (19) is similar to constraint (7), with the difference that now there will be assignments just in the bottleneck stations. Constraints (20) and (21) were created in order to fulfill the necessity of having a bottleneck station with a dedicated operator. Constraints (20) ensures that each bottleneck station gets assigned no more than one operator, while constraint (21) ensures that each operator is assigned to no more than one bottleneck station. Finally, constraint (22) is created in order to relate the bottleneck assignment to the final resulting assignment, \( A_{ijk} \). The bottleneck assignments, \( BA_{ijk} \), are an input to the sub model that will make the final assignment, \( A_{ijk} \). In order to create this constraint a new assignment variable, \( NA_{ijk} \), was introduced so that the sum of the bottleneck assignment plus the new assignments added must equal the final assignment decision variable. It is important to mention that all the constraints just introduced apply for the bottleneck model, with the difference that the final assignment decision variable, \( A_{ijk} \), is interchanged by the bottleneck assignment decision variable, \( BA_{ijk} \).

### 2.4 Final Model

Table 1 shows the objective function and constraints that each model stage contains. The numbers showed in the table represent the corresponding equations in the document.

<table>
<thead>
<tr>
<th>Model Stage</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Function</td>
<td>(2)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Constraints</td>
<td>(7)-(14), (19)-(21)</td>
<td>(4), (7)-(18), (22)</td>
<td>(4), (7)-(18), (22)</td>
</tr>
</tbody>
</table>
3. Numerical Example

This section discusses a hypothetical case composed of 5 cells with a variable number of stations by cell, an operational policy of 8 hours per shifts, and 23 operators. A capacity analysis made for the case is discussed, followed by the model results.

3.1 Capacity Analysis

An important parameter in this model is the number of operators available in the system. The number of operators needed should be calculated through a capacity analysis that depends primarily on the stations’ standard time (ST), and the demand units imposed in each cell, which are shown in Tables 2 and 3.

Table 2. Units demand per cell

<table>
<thead>
<tr>
<th>Cell</th>
<th>Demand (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
</tr>
</tbody>
</table>

Using the cell demand, stations’ ST’s, and total shift time, the time requirement or shift fraction required for each station in order to comply with the demand units of the cell can be calculated with Equation 23.

\[
\text{Shift fraction} = \frac{\text{Station Required Time}}{\text{Total Available Time}} = \frac{\text{Cell Demand Units} \times ST}{\text{Total Shift time}}
\]  (23)

It is important to mention that the standard time used in this model should be the result of a time study conducted at the selected manufacturing environment. A time study offers a standard time that includes allowances to account for the many interruptions, delays, and slowdowns caused by fatigue in every work assignment. Allowances normally adjudicated to workers in this environment are fatigue, personal needs, workstation cleaning, and unavoidable delays [15]. Table 4 shows the amount of operators needed for each cell.

Table 3. ST and shift fraction by station for cell 2

<table>
<thead>
<tr>
<th>Cell</th>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>ST (min)</td>
<td>3.1</td>
<td>3.4</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Shift fraction</td>
<td>0.74</td>
<td>0.81</td>
<td>0.65</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Table 4. Operators required in the system

<table>
<thead>
<tr>
<th>Cell</th>
<th>Shift fraction required</th>
<th>Operators required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.33</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>2.80</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>6.12</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>5.13</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>5.43</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Operators</td>
<td>22.80 (23)</td>
</tr>
</tbody>
</table>

Since the production demand for each cell has to be achieved, in order to reach demand in just one shift, the number of operators has to be greater than or equal to the total shift fraction needed for complying demand in a cell. We can see through the capacity analysis that it is important to understand that the total number of operators needed in the system is not always the sum of the shift fractions needed in each cell. This will depend on the assignment policy used in the system; intracell or intercell assignment. When there is an intracell assignment policy each cell is treated separately as an individual system and the total number of operators needed to meet demand is the sum of the operators required for each cell. On the other hand, when there is an intercell assignment policy the total number of operators is calculated through the total shift fraction in the whole system.
3.2 Results
The linear model was programmed in LINGO 11. For the intercell case composed of 23 operators we first start by discussing the results of the bottleneck assignments. As expected, the bottleneck assignments provided an operator with the highest skill, and between those with highest skill, it assigned the one with the highest preference. This is shown in figure 4 for cell 5, where operator 7 was selected.

The total system skill-satisfaction was increased from 38.21 in stage 2, to 56.24 in stage 3. Table 5 and Figure 5 summarizes the numbers for stages 2 and 3 where it can be seen how by applying the third stage; the total system skill-satisfaction was increased, while leaving the minimum skill-satisfaction at the maximum possible value.

4. Conclusions and Future Research
This section will provide a brief conclusion of the work previously discussed, followed by different alternatives that are considered as possible future work opportunities to expand the scope of this work.

4.1 Conclusions
This work proposed a linear programming model that takes into account the operators’ skills and preferences in order to maximize the resulting skill-satisfaction of their assignments. The model resolves the important issue of not considering operators’ preferences as a critical criteria in the decision making process of their assignment. Preferences may have a significant influence in an employee’s performance due to their emotional impact. If these are not considered, an operator with a high skill level in a certain area or work, but who prefers to be assigned to other areas can show some lack of interest, consequently lowering their performance.

Through the case study presented it was shown indeed that the model developed enhances the minimum skill-satisfaction and total system skill-satisfaction of operators, proving the model to be an acceptable and useful tool in the management decision making process of any company.

4.2 Future Work
The following are the topics considered as potential future work improvements for this research.

- Provide scheduling results in combination with the assignments.
- This work provides the assignment of operators and not the scheduling or order of the different tasks that these operators will perform. When an operator is partially assigned to several stations, it is understood that the
operator will be working a certain amount of the time in a station and the rest in another station(s). The problem of scheduling the order in which the operators will work those stations was not addressed here, but it is considered as a strong topic for future research.

- Modify the model for a Semi-Automatic Manufacturing Environment
  One of the limitations of this work is that the model applies to a system where cells perform only manual labor. This factor is a great opportunity for expanding the scope of this work. The current model could be modified to include the consideration of semiautomatic machines, where machines have to be loaded and unloaded, with an associated machine cycle time. The inclusion of this modification would open this model to a wider range of manufacturing plants.

- Modify the model to focus on the performance of cells and not the whole system.
  This model offers the option to select between an intercell and an intracell movement assignment policy. In an intracell movement assignment policy, cells are treated as independent systems. However, the objective functions in the model look to better the performance of the whole system, instead of the performance of each cell individually. The model could be modified so that when the user selects an intracell movement assignment policy, the objective functions look to maximize the operators’ minimum skill-satisfaction by cell, and the total system skill-satisfaction by cell.

References