A New Approach to Workforce Planning

M. Othman, N. Bhuiyan, and G. J. Gouw

Abstract**—**In today's global and competitive market, manufacturing companies are working hard towards improving their production system performance. Most companies develop production systems that can help in cost reduction. Manufacturing systems consist of different elements including production methods, machines, processes, control and information systems. Human issues are an important part of manufacturing systems, yet most companies do not pay sufficient attention to them. In this paper, a workforce planning (WP) model is presented. A non-linear programming model is developed in order to minimize the hiring, firing, training and overtime costs. The purpose is to determine the number of workers for each worker type, the number of workers trained, and the number of overtime hours. Moreover, a decision support system (DSS) based on the proposed model is introduced using the Excel-Lingo software interfacing feature. This model will help to improve the interaction between the workers, managers and the technical systems in manufacturing.

Keywords**—**Decision Support System, Human Factors, Manufacturing System, Workforce Planning.

I. Introduction

IN today's global market, customers have become more demanding and seek more variety, lower cost, and superb quality. In this competitive environment, companies develop efficient production systems that contribute towards continuously increasing customer satisfaction. Workforce planning is a deep and far-reaching subject that occupies a position close to the core of manufacturing management. It ensures having the right people at the right place at the right time to meet the company's employment needs. This includes planning for recruiting (new employees), firing extra workers, and training (internal employees). Most companies often find that the traditional approaches to workforce planning are ineffective, and that the expected benefits are not realized. Thus, a new approach for workforce planning is developed in this paper to help to make the implementation of the plan much easier in practice. The workforce planning module determines what workforce is needed to support production. Options which can be used to increase or decrease capacity to match current demand include: hiring workers, firing workers, cross training workers, overtime, part time workers and the use of temporary workers. Most manufacturing planning systems are becoming more complex in order to improve the productivity and the flexibility of the production operations. Various planning models are used to develop optimized plans that meet the demand at minimum cost or fill the demand at maximized profit. These optimization problems differ because of the differences in the manufacturing and market context. Most managers find that existing production planning models are not being implemented in practice [1]. A major problem with existing models is the lack of information about the actual situation on the shop floor regarding the condition of the workers and the uncertainties inherent in the production system. In recent years, research has highlighted the importance of interactions between some key human factors and the production system and the need to incorporate organizational behavior issues in operations management [2], [3]. The advantages derived from integrating human factors with production systems have been discussed [4], [5]. These benefits have been established through surveys and actual implementations. In highly competitive companies, this integration has helped to increase productivity, reduce throughput times, and improve product quality. These findings present a significant research opportunity. The main objective of this paper is to develop new approach for workforce planning problem to support the production planning process for optimal performance. A decision support system (DSS) is developed to aid managers with the practical implementation of the model.

The paper is organized as follows: Section II presents a literature review of human factors and their relation to production planning. Section III discusses the proposed workforce planning model. Next, Section IV presents the preliminary results generated from the proposed model. Finally, conclusions and future research directions are presented in Section V.

II. Literature Review

Typically, Human Factors (HF) are considered too late in system design. However, a research study has shown that 50-75% of implementations of modern manufacturing technologies were not successful [6] because most companies failed to integrate HF into the production system. More specifically, if HF are considered at the early stages of the planning process, management can develop more accurate production plans, leading to reduced production time and cost. There are specific challenges in integrating human issues into production planning because people differ from one another. In reality, there is a tremendous variability in individual capabilities. The result is that most production system designs ignore the effects of the human differences in production

M. Othman is with the Mechanical and Industrial Engineering Department, Concordia University, Montreal, Quebec, Canada H3G 1M8 (phone: +1514-836-3771; fax: +1514-848-3175; e-mail: mohothman2002@yahoo.com).

N. Bhuiyan is with the Mechanical and Industrial Engineering Department, Concordia University, Montreal, Quebec, Canada H3G 1M8 (e-mail: bhuiyan@alcor.concordia.ca).

G. J. Gouw is with the Mechanical and Industrial Engineering Department, Concordia University, Montreal, Quebec, Canada H3G 1M8 (e-mail: gouw@alcor.concordia.ca).

system design. The impact of worker differences on the production system was studied since individual differences can result in substantial loss in throughput [7]. The effects of the human, technology and organizational aspects on the outcome of the production scheduling processes were also studied by [8]. Based on their study, schedulers need to consider uncertainty, their experience, problem solving, workers differences, technical system limitations, the degree of proximity between employees and their informal authority. Different approaches and tools were developed in the Scandinavian countries [9]. He explained that the changes in the ergonomics role inside a company require understanding the organizational prerequisites. He proposed a political agent in order to complement the roles of an expert and a facilitator. He suggested developing studies on management of ergonomics and organizational development.

There is a small body of approaches that have been proposed for solving the workforce planning problem. A mixed integer programming model that considers worker differences in workforce planning was developed by [10]. They used the general cognitive ability metric to model individual difference in efficacy of cross-training and worker productivity. Also, a simulation model to evaluate the effectiveness and robustness of different planning options and assignment rules was developed [11]. Previous research has determined that the worker assignment strategies, worker skills, training, communication, autonomy, reward/compensation system, teamwork aspects, and conflict management need special attention for companies implementing cellular manufacturing [3]. A mathematical model to deal with a simultaneous dynamic cell formation and worker assignment problem was developed by [2]. They discussed the importance of incorporating the human issues into traditional dynamic cell formation. In their model, they considered some human issues such as hiring and firing workers, training, salary and workers' skills. Moreover, they concluded that considering the learning curve and other human issues in the model would be a promising area of work in future research. A MIP model for assigning workers to manufacturing cells in order to maximize the profit was presented [12]. The model considered both technical skills and human skills. Results indicate that the model provides better worker assignments than the one considering only technical skill.

The literature on production planning models that consider the human aspects was also surveyed. It was found that many quantitative models on aggregate planning, master scheduling and material planning including optimization, heuristics, and simulation have been developed [13]-[26]. There have been many interesting developments on the technical side of planning and control, but, all of these models ignored most, if not all, of the important human factors that can be critical for production planning performance. This provides the motivation to work towards developing a more comprehensive model that includes manufacturing and human parameters.

III. Model Description

In this paper, we assume that we have a manufacturing company that has different machines types, which are grouped into several machine levels depending on their complexity. The company produces several products on different machine types based on the products' routing sheet. Also, we assume that we have flexible routing which means that every operation of products can be processed on more than one machine with different processing times. Worker flexibility has been considered in order to reduce the manufacturing system variability. It can be achieved by using overtime, training, and temporary workers assignment. Workers are grouped according to different human skills. Each worker has at least one skill level and can be assigned to certain machine levels. In each period, workers can be trained in order to improve communication and increase workers' learning. In many cases, training is better than firing and hiring new workers. It is assumed that the training period is zero, which means that the worker is productive as soon as he is trained. Layoffs are never easy and do incur a human cost. When the company has a high percentage of layoffs, the loyalty to the company will be decreased. Also, most companies use labour laws and contracts to control the firing of workers. However, hiring new workers affects the performance of the present workers because they need to be trained to the same level of the previous fired workers. However, in order to satisfy the total demand of each period, we are interested in determining:

1) How many workers to assign to each machine level in each period.
2) How many workers, with which skill levels to hire or fire in each period.
3) How many workers to train from lower skill level to higher one in each period.

A. Assumptions

1) The values of all parameters are certain over the planning horizon.
2) Cost of hiring, firing and training workers are known and constant for each skill level.
3) The availability of all workers is assumed to be equal to 80% by considering daily breaks.
4) The number of worker skill levels is equal to the number of machine levels.

B. Mathematical Modeling

The model developed is a nonlinear programming model that allows a number of different staffing decisions (e.g. hire, train, fire and overtime) in order to minimize the sum of hiring, firing , training and overtime costs over all periods. In presenting the model, the following notations are used.

1. Indices

t = Index of planning periods (weeks), $t = 1,2,...,T$

j, k = Index of human skill levels, $j, k = 1,2,..., S$

x, y = Index of machine levels, $1,2,...,ML$

2. Parameters

h_{jt} = Cost of hiring a worker with skill set j in period t (\$/worker-week)

f_{jt} = Cost of lay-off of a worker with skill set j in period t (\$/worker-week)

tr_{kjt} = Cost of training a worker from skill set k to skill set j in period t (\$/worker-week)

so_{jt} = Hourly rate of a worker with skill set j at overtime in period t (\$/worker-hour)

A_{jt} = Available regular working hours of a worker with skill set j for each person in each period t (worker-hours/worker-week)

AOT_{jt} = Available overtime working hours of a worker with skill set for each person in each period t (worker-hours/worker-month)

D_{jt} = Demand for skill j in period t (worker-hours)

$$ss_{kj} = \begin{cases} 1 & \text{If training from skill level } k \text{ to skill level } j \text{ is possible;} \\ 0 & \text{otherwise,} \end{cases}$$

$$ws_{jx} = \begin{cases} 1 & \text{If working on machine level } x \text{ with skill level } j \text{ is possible;} \\ 0 & \text{otherwise,} \end{cases}$$

INW_{jx} = Initial number of workers with skill set j required to be assigned to machine level x (worker-weeks)

M = A big number

3. Decision variables

W_{jtx} = Number of workers with skill set j required to be assigned to machine level x in period t (worker-weeks)

H_{jtx} = Number of workers with skill set j hired and assigned to machine level x in period t (worker-weeks)

L_{jtx} = Number of existing workers with skill set j who are assigned to machine level x in period $t-1$ and they are laid-off in period t (worker-weeks)

Y_{kjtyx} = Number of workers who were assigned to machine level y and then are trained from skill set k to skill set j and assigned to a higher machine level x in period t (worker-weeks)

OT_{jtx} = Overtime hours of a level workers with skill set j in period t (worker-hours)

4. Objective function:

The objective is to minimize costs over the time horizon:

Minimize:

$$Z = \sum_{t=1}^{T}\sum_{j=1}^{S}\sum_{x=1}^{ML}\left(h_{jt} \times H_{jgt} + f_{jt} \times L_{jtx} + so_{jt} \times OT_{jtx}\right) + \sum_{t=1}^{T}\sum_{j=1}^{S}\sum_{k=1}^{S}\sum_{x=1}^{ML}\sum_{y=1}^{ML}\left(tr_{jkt} \times Y_{jktxy}\right)$$

Subject to:

$$0.8 \times A_{jt} \times \left(\sum_{x=1}^{ML} W_{jtx}\right) + \sum_{x=1}^{ML} OT_{jtx} = D_{jt} \qquad \forall j,t,x \qquad (1)$$

$$W_{jtx} = W_{jt-1x} + H_{jtx} - L_{jtx} + \sum_{\substack{k=j-1 \\ j\geq 2}}^{j}\sum_{\substack{y=x-1 \\ x\geq 2}}^{x}\left(Y_{kjtyx}\right) - \sum_{\substack{k=j+1 \\ k\geq 2}}^{k}\sum_{\substack{y=x+1 \\ y\geq 2}}^{y}\left(Y_{jktxy}\right) \qquad \forall j,t,x \qquad (2)$$

$$OT_{jtx} \leq AOT_{jt} \times W_{jtx} \qquad \forall j,t,x \qquad (3)$$

$$\sum_{\substack{k=1 \\ k>j}}^{S}\sum_{y=1}^{ML} Y_{jktxy} + L_{jtx} \leq W_{j,t-1,x} \qquad \forall j,t,x \qquad (4)$$

$$L_{jtx} \leq M \times ws_{jx} \qquad \forall j,t,x \qquad (5)$$

$$H_{jtx} \leq M \times ws_{jx} \qquad \forall j,t,x \qquad (6)$$

$$Y_{kjtyx} \leq M \times ws_{ky} \qquad \forall j,k,t,x,y \qquad (7)$$

$$Y_{kjtyx} \leq M \times ws_{jx} \qquad \forall j,k,t,x,y \qquad (8)$$

$$Y_{kjtyx} \leq M \times ss_{kj} \qquad \forall j,k,t,x,y \qquad (9)$$

$$\sum_{k=1}^{S} Y_{kjtyx} \times L_{jtx} = 0 \qquad \forall j,t,x,y \qquad (10)$$

$$H_{jtx} \times L_{jtx} = 0 \qquad \forall j,t,x \qquad (11)$$

$$W_{jtx}, H_{jtx}, L_{jtx}, Y_{kjtyx} \geq 0 \qquad \forall j,k,t,x,y \qquad (12)$$

The objective function aims to minimize all costs incurred workers hiring and firing, training costs and overtime costs. Constraint (1) shows the total available worker hours is equal to the number of hours required for each skill in each period. Constraint (2) guarantees that the available workforce in any period equals workforce in the previous period plus the change of workforce in the current period. Constraint (3) ensures that the overtime workforce available should be less than the maximum overtime workforce available in each period. Constraint (4) ensures that the total number of workers who are assigned to machine level x in period t-1 and now fired or trained for upper skill levels should not be greater than the number of workers required in previous period. Constraint (5) ensures that workers can be fired if and only if the assignment is possible. Constraint (6) denotes that workers can be hired if and only if the assignment is possible. Constraint (7) Training for better skills is possible if and only if the previous assignment is possible. Constraint (8) ensures that training for better skills is possible if and only if the latter assignment is possible. Constraint (9) ensures that training for better skills is possible if and only if training to that skill is possible. Constraint (10) guarantees the workers who are trained for skill level *j* should not be fired in the same period. This constraint contains a nonlinear formula that can be transferred to a linear term with the help of a binary variable as follows:

$$\sum^{S} Y_{kjtyx} \leq M \times Z_{jtx} \qquad \forall j,t,x,y \qquad (13)$$

$$L_{jtx} \leq M\left(1 - Z_{jtx}\right) \qquad \forall j,t,x \qquad (14)$$

$$Z_{jtx} \in \{0,1\} \qquad \forall j,t,x \qquad (15)$$

Constraint (11) ensures that either hiring or firing workers occurs but not both. Also, this constraint has a nonlinear that can be transformed into linear one in the same way as the previous constraint, as follows:

$$H_{jtx} \leq M \times U_{jtx} \qquad \forall j,t,x \qquad (16)$$

$$L_{jtx} \leq M\left(1 - U_{jtx}\right) \qquad \forall j,t,x \qquad (17)$$

$$Z_{jtx} \in \{0,1\} \qquad \forall j,t,x \qquad (18)$$

Finally, constraint (12) is the non-negativity constraint.

IV. Computational Results

In this section, some data are used to illustrate the flexibility of the proposed nonlinear programming model (converted to integer linear one) for the workforce planning problem in order to demonstrate the application of the model.

A. Numerical Example

A company produces its products to fulfil known demand along a 6-weeks planning horizon. The hiring, and firing costs are assumed to be higher for higher skill levels. Also, it is assumed that the worker is available for 40 hours a week (160 hours per month) at regular time and he is available for 10 hours a week (40 hours per month) at overtime. Input data are shown in tables I-V. The known demand of worker skills in worker-hours in each period is summarized in Table I. Table II shows workers' availabilities. Hiring costs, lay-off costs, and overtime costs are shown in Table III. Table IV shows the available workforce at period zero. Finally, Table V shows the cost of training from skill level to another skill level in each period. Using the input data presented, the optimal solution can be easily obtained using LINGO 10 software. Results from the proposed model are shown in Table VI. The objective function value **is** $**14911.16.** One of the reasons existing models fail to give accurate results is that they are based on inadequate factors. To overcome this problem, it was decided to keep the number of human factors low and to choose those factors that seem to be more measurable and easier to understand to represent reality. In this paper, four human factors such as workers' training, workers' skills, overtime, and workers' availabilities are considered to show the importance of including these factors at the early planning stages. However, the results from the model offer staffing decisions on what, how and when to hire, fire and train. Also, the number of worker-hours during regular time and overtime is determined.

In the first week, the available worker hours at the beginning of the week are 256 hours; 90 worker hours are trained to skill 2, so we have only 166 hours during regular time.

TABLE I
DEMAND OF WORKER SKILLS IN EACH WEEK (worker-hours)

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Skill 1	320	150	320	220	200	300
Skill 2	350	300	350	320	300	250
Skill 3	380	280	380	280	300	200

TABLE II
WORKERS' AVAILABILITIES (worker-hours)

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Skill 1	regular time	40	40	40	40	40	40
	overtime	10	10	10	10	10	10
Skill 2	regular time	40	40	40	40	40	40
	overtime	10	10	10	10	10	10
Skill 3	regular time	40	40	40	40	40	40
	overtime	10	10	10	10	10	10

TABLE III
HIRING, FIRING AND OVERTIME COSTS ($/worker-weeks)

		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Skill 1	hiring	400	400	400	400	400	400
	firing	300	300	300	300	300	300
	overtime	20	20	20	20	20	20
Skill 2	hiring	500	500	500	500	500	500
	firing	350	350	350	350	350	350
	overtime	25	25	25	25	25	25
Skill 3	hiring	600	600	600	600	600	600
	firing	400	400	400	400	400	400
	overtime	30	30	30	30	30	30

TABLE IV
INITIAL WORKFORCE AVAILABLE IN EACH MACHINE LEVEL (workers)

	Level 1	Level 2	Level 3
Skill 1	8	0	0
Skill 2	0	10	0
Skill 3	0	0	10

TABLE V
TRAINING COSTS IN EACH PERIOD ($/worker-weeks)

From	To	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Skill 1	Skill 2	10	10	10	10	10	10
Skill 2	Skill 3	10	10	10	10	10	10

Thus, 77.8 worker hours must be hired to satisfy demand. However, the existing workers have the option to work overtime, so the maximum hours that the existing workers can work during overtime are:

$$OT_{111} = 10 \times \left[\frac{256 + 77.8 - 90}{32} \right] = 76.2\ hours$$

TABLE VI
RESULTING WORKFORCE PLAN

		Week 0	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Skill 1	Worker-hours Required		**320**	**150**	**320**	**220**	**200**	**300**
	Worker-hours used in Level 1	256	243.8	150	243.8	220	200	300
	Worker-hours used in Level 2							
	Worker-hours used in Level 3							
	Worker-hours Hired		77.8	0	243.8	0	0	100
	Worker-hours Fired		0	93.8	0	23.8	20	0
	Worker-hours Trained		90	0	150	0	0	0
	Overtime Hours		76.2	0	76.2	0	0	0
Skill 2	Worker-hours Required		**350**	**300**	**350**	**320**	**300**	**250**
	Worker-hours used in Level 1	0	0	0	0	0	0	0
	Worker-hours used in Level 2	320	350	300	350	320	300	250
	Worker-hours used in Level 3							
	Worker-hours Hired		0	0	0	0	0	0
	Worker-hours Fired		0	50	0	30	0	50
	Worker-hours Trained		60	0	100	0	20	0
	Overtime Hours		0	0	0	0	0	0
Skill 3	Worker-hours Required		**380**	**280**	**380**	**280**	**300**	**200**
	Worker-hours used in Level 1	0	0	0	0	0	0	0
	Worker-hours used in Level 2	0	0	0	0	0	0	0
	Worker-hours used in Level 3	320	380	280	380	280	300	200
	Worker-hours Hired		0	0	0	0	0	0
	Worker-hours Fired		0	100	0	100	0	100
	Worker-hours Trained		0	0	0	0	0	0
	Overtime Hours		0	0	0	0	0	0

In the second week, we need to fire only 93.8 worker hours in order to satisfy the demand (150 worker hours). Also, you can notice that the firing decisions are made based on the difference between the worker hours available and worker hours required in each period. Finally, we can conclude that by offering more capacity options for the model, the total cost will be reduced.

On the other hand, if the initial workforce at skill level 3 and machine level 2 is increased to be 1 worker or 32 hours, then the model reduces the number of hiring hours at skill 1 by 32 hours, and only 58 hours will be trained to skill level 2. At skill 2, we have 320 hours available, and 28 hours will be transfer to skill level 3, so we have 292 left. By adding the 58 hours that transferred from skill 1 to skill 2, total demand at skill level 2 will be satisfied. At skill level 3, the initial workforce is 320 hours working at machine level 3 and 32 hours working at machine level 2, so we only need to add the 28 hours that are transferred from skill 2 to skill 3 to satisfy the demand at the first period. Also, you can notice that at period 2 the 32 hours of skill 3 working at machine level 2 is fired first because there is no need to making workers with high skill to work in low machine levels. The rest of the results in other periods do not change.

B. *Decision Support System*

A decision support system based on Lingo-Excel interfacing concept is proposed. To begin, a system user has to enter the historical demand in each period. Then, hiring, firing, training costs, regular and overtime salary must be input. Fig. 1 shows the presentation menu for the input data. The user will then have different scenarios to choose from. The program includes “switches” to turn features on or off, yes or no (1 is on/yes, 0 is off/no) to make selections among training, salary, objective function and overtime options as shown in Fig. 2. The effect of these switches is that we change the constraints in the actual Lingo model.

However, it can be cumbersome and impractical to try to maintain workforce data in a LINGO model file. For this reason, LINGO program is linked to Excel through real-time Object Linking and Embedding (OLE) feature. OLE automation links can be used to drive LINGO from Excel macros, and embedded OLE links that allow you to import the functionality of LINGO into Excel. However, the computerized DSS presented herein makes the model a useful problem solving tool for managers. The system has been designed to have an efficient interface with Excel, so the user can import input data directly from the organization’s database and export the output of the model to other database in the organization.

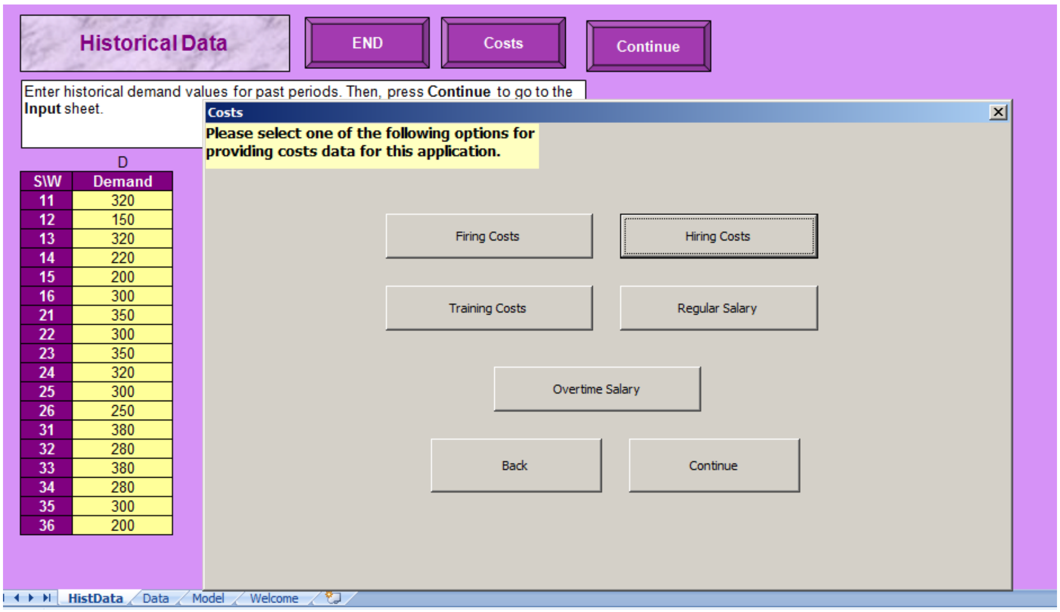

Fig. 1 Presentation menu

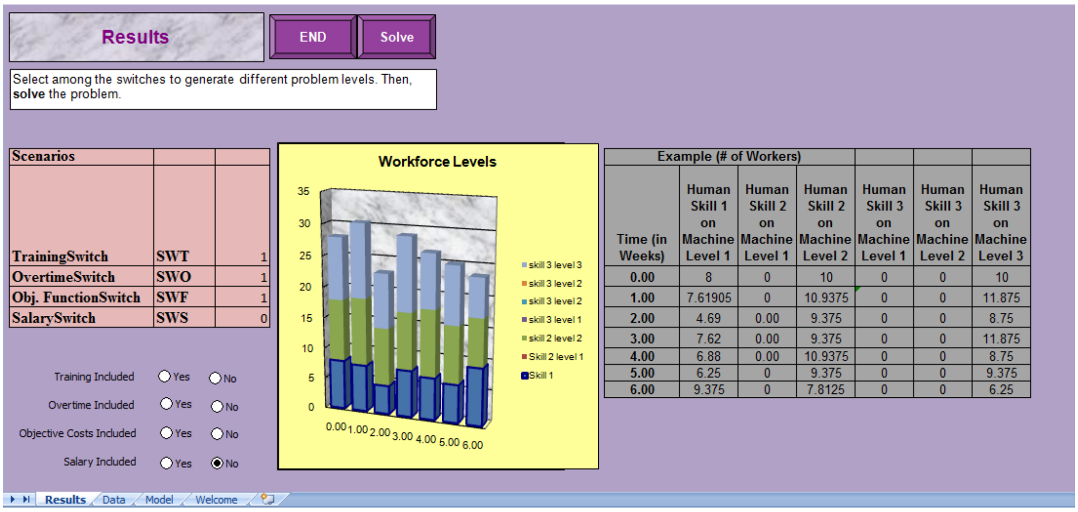

Fig. 2 Generated results

The results obtained from solving the optimized model show that if the workforce planning model considers human factors such as skills, training, availability, and other real human issues, we may be able to make better decisions regarding production and employees. For instance, by using a plan that considers the worker's skills and training, the decision of assigning the right worker to a right machine level at the right time will be made without need to modify the scheduling process every period so that the total cost and time will be reduced. Moreover, if the initial number of workers is changed, the number of hired, fired or trained workers is changed, which will change the total costs. These findings provide motivation towards making the proposed model represent the current production systems in industrial companies.

V. CONCLUSION

A preliminary workforce planning model has been developed in order to concentrate on human issues in production planning. The model allows a number of different staffing decisions (e.g. hire, train, fire, and overtime) in order to minimize the sum of hiring, firing, training and overtime costs over all periods. Human issues such as workers breaks, vacations, availability, training period, and retirement are considered. The workforce planning model has been developed from scratch by adding each human issue step by step in order to verify the generated results.

Specific contributions of this paper include: developing a workforce planning model that considers workers' differences, workers' training, and workers' skills, workers' availabilities Also, the working levels and possibility of workers training and upgrading are considered. The results show that costs have a significant effect on the selection of the workers with different skill ability. In addition, a decision support system is presented to enhance the application of the workforce planning model in practice.

It is clear that research on workforce planning has not come to an end, and the path is still open to make the proposed model more comprehensive and more realistic. It may consider other human factors such as learning curves, worker motivation and experience which can be a promising area of work for future research. However, learning curve effects should be considered in formulating the model. In assembly activities that require more manual work, it has been observed that production time decreases as workers learn more about their work and how to perform it, and their experience increases. Also, refining the proposed model to consider worker experience would be another approach to integrate human related aspects into production planning. For example, labour wages can be a function of time and experience which reflects the current systems that management uses in different companies. Finally, motivation should be linked to productive performance to evaluate a human-job fit in the planning process. On the other hand, future research might consider the development of an interactive DSS that will help managers to solve the model in the context of uncertainty of demand and costs parameters.

In conclusion, the research has demonstrated the importance of considering human factors early in the planning process of manufacturing systems. It is one of the attempts to bridge the gap between the theory and practice of production planning models. By considering the technical and human factors, the proposed model can be used as a tool to support real world decision-making processes in a manufacturing system.

REFERENCES

[1] M. D. Byrne, and M. A. Bakir, M.A., "Production planning using a hybrid simulation-analytical approach," *International Journal of Production Economics,* vol. 59, no. 305–311, 1999.

[2] M. B. Aryanezhad, V. Deljoo, and S. M. J. Al-e-hashem, "Dynamic cell formation and the worker assignment problem: a new model," *The International Journal of Advanced Manufacturing Technology,* vol. 41, no. 3-4, pp. 329–342, 2009.

[3] B. Bidanda, P. Ariyawonggrat, K. M. Needy, B. A. Norman, and W. Tharmmaphornphilas, "Human related issues in manufacturing cell design, implementation, and operation: a review and survey," *Computers & Industrial Engineering,* vol. 48, no. 507–523, 2005.

[4] P. Oborski, "Man-machine interactions in advanced manufacturing systems," *International Journal of Advanced Manufacturing Technology,* vol. 23, no. 3-4, pp. 227-232, 2004.

[5] G. Udo and A. Ebiefung, "Human factors affecting the success of advanced manufacturing systems," *Computers & Industrial Engineering,* vol. 37, pp. 297–300, 1999.

[6] C. W. Clegg, *et al.*, "An international survey of the use and effectiveness of modern manufacturing practices," *Human Factors and Ergonomics in Manufacturing,* vol. 12, no. 2, pp.171–191, 2002.

[7] J. A. Buzacott, "The impact of worker differences on production system output," *International Journal of Ergonomics Economics,* vol. 78, no. 37–44, 2002.

[8] M. Berglund, and J. Karltun, "Human, technological and organizational aspects influencing the production scheduling process," *International Journal of Production Economics,* vol. 110, no. 1-2, pp. 160–174, 2007.

[9] P. L. Jensen, "Human factors and ergonomics in the planning of production," *International Journal of Industrial Ergonomics,* vol. 29, pp. 121–131, 2002.

[10] P. Wirojanagud, E. S. Gel, J. W. Fowler, and R. Cardy, "Modeling inherent worker differences for workforce planning," *International Journal of Production Research*, vol. *45, no.* 3, pp. 525–553, 2007.

[11] H-C. Huang, L-H. Lee, H. Song, and B. T. Eck, "SimMan-A simulation model for workforce capacity planning," *Computers & Operations Research,* vol. 36, no. 8, pp. 2490-2497, 2008.

[12] B. A. Norman, W. Tharmmaphornphilas, K. L. Needy, B. Bidanda, and R. C. Warner, "Worker assignment in cellular manufacturing considering technical and human skills," *International Journal of Production Research* vol. 40, no. 6, pp. 1479–1492, 2002.

[13] Y. Y. Lee, "Fuzzy set theory approach to aggregate production planning and inventory control," Ph.D. Dissertation. Department of I.E., Kansas State University, 1990.

[14] J. B. Mazzola, A. W. Neebe, and C. M. Rump, "Multiproduct production planning in the presence of work-force learning," *European Journal of Operational Research*, vol. 106, no. 2-3, pp. 336–356, 1998.

[15] R. C. Wang, and H. H. Fang, "Aggregate production planning with multiple objectives in a fuzzy environment," *European Journal of Operational Research,* vol. 133, pp. 521-536, 2001.

[16] J. Tang, R. Y. K. Fung, and K-L. Yung, "Fuzzy modeling and simulation for aggregate production planning," *International Journal of Systems Science,* vol. 34, no. 12–13, pp. 661–673, 2003.

[17] R. C. Wang, and T. F. Liang, "Application of fuzzy multi-objective linear programming to aggregate production planning," *Computers & Industrial Engineering,* vol. *46,* pp. 17–41, 2004.

[18] L. Pradenas, and F. Peñailillo, and J. Ferland, "Aggregate production planning problem. A new algorithm," *Electronic Notes in Discrete Mathematics,* vol. 18, pp. 193–199, 2004.

[19] A. Jain, and U. S. Palekar, "Aggregate production planning for a continuous reconfigurable manufacturing process," *Computers & Operations Research*, vol. 32, no. 1213–1236, 2005.

[20] R. C. Wang, and T. F. Liang, "Applying possibilistic linear programming to aggregate production planning," *International Journal of Production Economics*, vol. 98, pp. 328–341, 2005.

[21] C. G. Da Silva, J. Figueira, J. Lisboa, and S. Barman, "An interactive decision support system for an aggregate production planning model based on multiple criteria mixed integer linear programming," *The International Journal of Management Science,* vol. 34, no. 167–177, 2006.

[22] S. Leung, and S. Chan, "A goal programming model for aggregate production planning with resource utilization constraint," *Computers and Industrial Engineering,* vol. 56, pp. 1053–1064, 2009.

[23] A. Jamalnia, and M. A. Soukhakian, "A hybrid fuzzy goal programming approach with different goal priorities to aggregate production planning," *Computers & Industrial Engineering,* vol. 56, no. 4, pp. 1474-1486, 2009.

[24] J. Tang, R. Y. K. Fung, and K-L. Yung, "Fuzzy modeling and simulation for aggregate production planning," *International Journal of Systems Science,* vol. 34, no. 12–13, pp. 661–673, 2003.

[25] S. C. K. Chu, "A mathematical programming approach towards optimized master production scheduling," *International Journal of Production Economics,* vol. 38, no. 2-3,pp. 269–279, 1995.

[26] S. J. Nam, and R. Logendran, "Aggregate production planning – A survey of models and methodologies," *European Journal of Operational Research,* vol. 61, no. 255–272, 1992.