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Trends and Opportunities

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A Service Production Planning Model Integrating Human Risk Factors

Nguyen Vi Cao and Emmanuel Fragniere

Abstract

Most models of production planning based on mathematical programming tend to assume constant technical coefficients. This assumption is realistic when the production is based on machines as it is the case in manufacturing. On the other hand, production planning in the service sector involves humans instead of machines. Consequently, the assumption that all technical coefficient of the mathematical program are constant cannot hold anymore. This is especially the case for productivity parameters related to human activity. It is well known for instance that in the service sector when administrative tasks are repetitive and boring, working overload has a direct impact on the employee productivity.

We have adapted a manufacturing planning model producing industrial goods into a service production planning model. In this service model, employees with different job status (junior, senior and expert) are handling cases of specific difficulties (simple, standard, personal and special). Then, we have introduced a variable productivity formula into the mathematical program that takes into account “plateau” levels assuming diminishing productivities. To do so the mathematical program includes integer variables as well as non-linearity and thus becomes a NLMIP (Non Linear Mixed Integer Program).

A fictitious case study is presented. The initial service production planning model with constant technical coefficient leads to solutions involving job specialization. On the other hand the model version with the variable productivity formula offers a better workload balance and more possibilities of job polyvalence reducing thus human risks such as burn-outs.

Keywords: human factor, production planning optimization, risk, service

1. Context and literature review

Human failures such as "burn-out" can impact negatively the overall supply chain. Even if this kind of "work disease" is well studied by psychologists, it is usually not integrated in production planning models. We posit that human risks are as significant as any other "conventional" production risks such as machine breakdowns or bottlenecks. This is particularly relevant in the case of service supply chains that are generally labor intensive.

Production planning models are typically described by technical input/output data. Besides these technical aspects, we introduce “soft” variables that model human risk factors like stress, fatigue or lack of motivation.

Our work to include soft variables in mathematical programs started a few years ago. At that time, the authors of this paper were working with sociologists. We developed a production optimization model adapted to couple matching (Cao et al., 2010). The goal was to optimize romantic partner attributes, and to assess how far from the optimum is the current situation. Therefore, assessing the extent to which couples are paired optimally could be realized in the light of the minimization of divorces and separations.

Reviewing the recent literature on aggregate production planning models and general production optimization models, we have noticed that the 2 main currents in research are related to the inclusion of the notion of risk in supply chain models (stochastic programming) and to the development of complex non-linear models. Thomson and Goodale (2006) are for instance exploring the notion of variable productivity through stochastic techniques. Valls et al. (2009) integrate the notion of skilled workforce with different categories of abilities. Eitzen et al. (2004) are addressing the case of multiple skills in production planning.

However to our knowledge very few research developments are devoted to the integration of soft or behavioral variables in production optimization models. For instance, the notion of flexibility as a human factor has been investigated in the context of supply chain by More and Badu (2009). MCkAy and Wiers (2006) have studied the qualitative aspects of human expertise in planning and scheduling functions.

In our paper, we assume different job statuses and thus levels of expertise (or tacit knowledge) which is to our knowledge a novel approach in production planning optimization. Closer to our modeling approach, Othman et al. (2012) are minimizing the worker's fatigue. Roland et al. (2010) model the well being of the medical staff in the scheduling model.

If we consider fields such as work psychology or behavioral organization, we notice that a lot of effort is dedicated to the study of this kind of soft variables. Let us take as an example the seminal paper by Hackman and Oldham (1976) on the notion of motivation. Unfortunately, these kind of scientific findings are rarely taken into account in production optimization models. In consequence, we believe that it is important to establish more links between management science and social sciences in order to give more realism to production planning models.

This paper is organized as follows. In Section 2, we explain how we have adapted a manufacturing planning model producing industrial goods into a service production planning model. In Section 3, we propose a variable productivity formula that takes into account "plateau" levels assuming diminishing productivities. In Section 4, we present the complete mathematical program with the variable productivity formula. In Section 5, we develop a fictitious case study involving both models. Results of both models are compared. Finally in Section 6, results are discussed and we conclude, in Section 7, with further research directions.

2. A production planning model for services

The original model structure is called "Ajax Paper Company Production Schedule" (CDC, 1977). It comes from the GAMS library of models, the well known algebraic modeling language. A paper manufacturer can produce four different types of paper on three different machines. Given a fixed capacity of each machine, a fixed productivity of each machine for the production of each type of paper, a fixed cost of each machine to produce each type of paper, a fixed demand schedule and a fixed price of each type of paper, the objective is to find a production plan that maximizes the monthly profit.

In this paper, we propose to apply the Ajax model in the case of services production that can typically be found in public administrations, advocacy offices, audit companies, fiduciaries, notaries, etc. In these companies, employees handle usually a large number of cases.

The analogy between the Ajax model with a production of tangible goods and a services production is done as follows:

- The industrial production corresponds to administrative or consulting tasks
- The goods output corresponds to cases that are handled
- The machines correspond to employees working in an administration

The mathematical formulation of the service production model is as follows:

Given:

e	employee
c	specific type of cases to handle
h_e	number of weeks the employee *e* can work
$p_{e,c}$	fixed productivity of the employee e for the case *c*
$k_{e,c}$	cost of the employee *e* to handle the case *c*
d_c	demand for the case *c*
v_c	price the client is asked to pay for case *c*
$x_{e,c}$	amount of case *c* to be produced by the employee *e*

$$max \sum_c \sum_e (v_c - k_{e,c})\, x_{e,c} \qquad (1.1)$$

Subject to

$$\sum_c \frac{x_{e,c}}{p_{e,c}} \leq h_e \qquad \forall e \qquad (1.2)$$

$$\sum_e x_{e,c} = d_c \qquad \forall c \qquad (1.3)$$

$$x_{e,c} \in \{0, 1, 2, \ldots\} \qquad (1.4)$$

Equation (1.1) represents the objective function. The overall profit of the production system is maximized. Equation (1.2) represents the capacity of production constraints. The workload of each employee is up to the number of weeks he can do. Equation (1.3) represents the demand constraints. The total cases handled must be equal to the demand for all types of cases. Equation (1.4) represents the non negativity constraints. The numbers of cases to be handled are non negative variables as in the Ajax initial model but it is important to notice that in our service production model continuous variables are replaced by discrete integer variables.

3. A productivity variation formula

In the model presented in Section 3, the machines productivity is constant. In the case of service production, human productivity is not as stable as machine productivity. We assume that when an employee has to handle over a certain amount of cases, its productivity decreases. It is due to fatigue, stress and lack of concentration. The employees are inclined to slow down their working activity and are then prone to make more mistakes creating quality issues. We suggest integrating human factor in the model by introducing a productivity variation.

There are many ways to vary the productivity. Below we suggest a simple manner to do that.

Given:

$p_{e,c}$ standard productivity of employee *e* for the case *c*

$t_{e,c}$ threshold that reduces the productivity of employee *e* for the case *c*

$r_{e,c}$ productivity reduction each time the threshold $t_{e,c}$ is reached

The productivity variation of employee e for the case c is given as shown below

$$p_{e,c} - \left\lfloor \frac{x_{e,c}}{t_{e,c}} \right\rfloor r_{e,c} \qquad (2.1)$$

Formula (2.1) is based on a “plateau” logic. Each time a worker reaches a threshold, its productivity is reduced. With this formula, productivity passes from the constant status to the variable status. The value of the productivity variable depends on the production plan i.e. the final decision and affects the workload of the employees, i.e. the capacity constraint.

4. The planning model with productivity variation

We can now introduce the productivity variation formula (2.1) into the service production mathematical model above to have a new model that takes into account the human factor. This formula is simple but it is important to notice that it introduces a non linearity into the initial model.

Given:

e employee

c specific type of cases to handle

h_e number of weeks the employee *e* can work

$p_{e,c}$ fixed productivity of the employee *e* for the case *c*

$k_{e,c}$ cost of the employee *e* to handle the case *c*

d_c demand for the case *c*

v_c price the client is asked to pay for case *c*

$t_{e,c}$ threshold that reduces the productivity of employee *e* for the case *c*

$r_{e,c}$ productivity reduction each time the threshold $t_{e,c}$ is reached

$x_{e,c}$ amount of case *c* to be produced by the employee *e*

$$max \sum_c \sum_e (v_c - k_{e,c})\, x_{e,c} \qquad (3.1)$$

Subject to

$$\sum_c \frac{x_{e,c}}{\left(p_{e,c} - \left\lfloor \frac{x_{e,c}}{t_{e,c}} \right\rfloor r_{e,c}\right)} \leq h_e \qquad \forall e \qquad (3.2)$$

$$\sum_e x_{e,c} = d_c \qquad \forall c \qquad (3.3)$$

$$x_{e,c} \in \{0, 1, 2, \dots\} \qquad (3.4)$$

5. Case study

In this section we create a data set representing a fictive service production in a fiduciary. We implement the initial service production model and then the same model with a variable productivity using the same data set. We solve both models and discuss the results.

In the company there are 3 job statuses: junior, senior and expert. In terms of cases to handle, there are 4 categories of cases: simple, standard, personal and special. Job status and case categories are both defined over ordinal scales. Table 1 provides working time figures in weeks in function of the job status. Table 2 indicates the employee productivity figures according to job status as well as case categories. Table 3 shows the unit production cost in $ per employee job status in function of the case categories. Finally, Table 4 provides the demand of cases per category and the price per case category.

	Junior	Senior	Expert
Number of weeks	4	3	2

Tab. 1: Employee working time

	Junior	Senior	Expert
Simple case	40	45	50
Standard case	20	25	30
Personal case	10	15	20
Special case	5	8	10

Tab. 2: Employee productivity (cases per employee per week)

	Junior	Senior	Expert
Simple case	30	40	50
Standard case	60	70	80
Personal case	140	120	100
Special case	280	240	200

Tab. 3: Production cost ($ per case per employee)

	Demand	Price
Simple case	82	80
Standard case	36	100
Personal case	25	150
Special case	17	300

Tab. 4: Demand and Price

	Junior	Senior	Expert	Total	Demand
Simple case	82	0	0	82	82
Standard case	36	0	0	36	36
Personal case	0	11	14	25	25
Special case	0	4	13	17	17

Tab. 5: Production (case per employee)

	Junior	Senior	Expert	
Simple case	2.05	0.00	0.00	
Standard case	1.80	0.00	0.00	
Personal case	0.00	0.73	0.70	
Special case	0.00	0.50	1.30	Total
Total	3.85	1.23	2.00	7.08
Max capacity	4.00	3.00	2.00	9.00

Tab. 6: Workload (week per employee and per case)

The model instance is solved using the GAMS modeling language and an appropriate solver. The optimal production plan is displayed in Tables 5 and 6 below. Table 5 indicates the repartition of cases to job status. Table 6 indicates the workload considering the case category as well as the job status.

Table 5 and Figure 1a show a complete specialization for juniors in simple and standard cases and for seniors and experts in personal and special cases. It is because cases are assigned to employees having the lowest production cost in order to maximize the profit. Table 6 and Figure 1b show an unbalanced workload as the junior employee works 3.85 weeks over 4, the expert employee 2 weeks over 2 while the senior employee works only 1.23 week over 3.

As a subsequent analysis, we have developed an additional instance of the model, with the same initial data, except that we have included the productivity variation formula (2.1) in the model along with a specific data set presented in Table 7. We see in this table that for instance when the working load reaches the threshold of 40 simple cases per week, it involves a reduction in productivity of 5 cases per week. The logic of this decline is based on the idea that simple cases are routinely handled and when their quantity is growing to a certain extent (threshold), employees are more tired and less motivated.

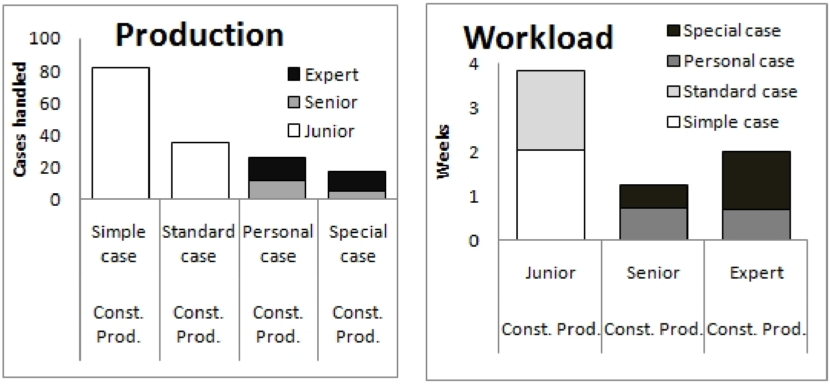


Fig. 1a and 1b: Production (case per employee) and Workload (week per employee and per case) in the constant productivity model

	Threshold	Reduction
	(cases)	(case per week)
Simple case	40	-5
Standard case	20	-3
Personal case	10	-2
Special case	5	-1

Tab. 7: Productivity reduction

The optimization of the new instance including the human variable productivity provides a different production plan. Results are presented in Tables 8 and 9 below. The optimization of this model does not lead to a global optimum since the structure of the model falls into the category of non-linear mixed integer programs that are non convex. In this case study, we have made sure that the presented solution is feasible since we have no guaranty that it is a global optimum. This model thus presents interesting algorithmic issues that will be addressed in another paper.

	Junior	Senior	Expert	Total	Demand
Simple case	81	1		82	82
Standard case	22	14		36	36
Personal case		7	18	25	25
Special case		8	9	17	17

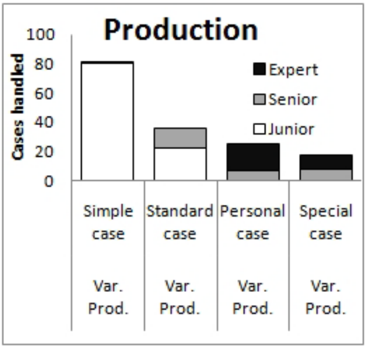
Tab. 8: Production (case per employee)

	Junior	Senior	Expert	
Simple case	2.70	0.02	0.00	
Standard case	1.29	0.56	0.00	
Personal case	0.00	0.47	1.00	
Special case	0.00	1.14	1.00	Total
Total	3.994	2.192	2.000	8.19
Max capacity	4.00	3.00	2.00	9.00

Tab. 9: Workload (week per employee)

On one hand, we notice in Table 8 and Figure 2a a rebalancing of simple and standard cases to the senior employee who is now more involved in low key activities to ease the workload of the junior employee. Table 9 and Figure 2b show also a better workload balance as the senior employee works now 2.192 weeks over 3 compared to 1.2 weeks over 3 in the constant productivity model.

The workload of the junior employee increases only slightly while the expert's workload remains constant.



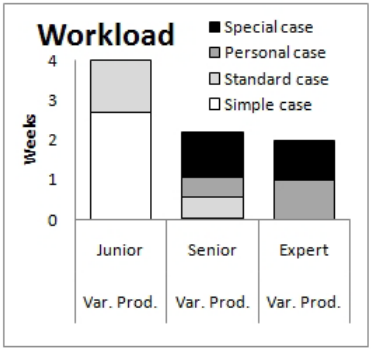
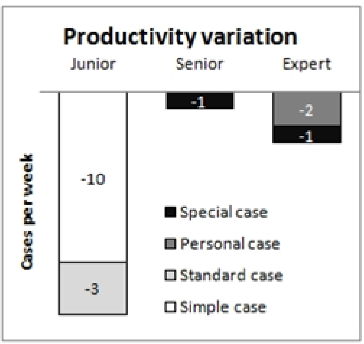


Fig. 2a and 2b: Production (case per employee) and Workload (week per employee and per case) in the variable productivity model

On the other hand, the productivity of the employees decreases for some type of cases (see Figure 3a). Besides, Figure 3b indicates that the total profit in the variable productivity model is about 2% lower than in the constant productivity model. It shows that it has a cost to prevent human risk to happen. Moreover, we also need to accept that today hyper specialization is not tenable anymore.



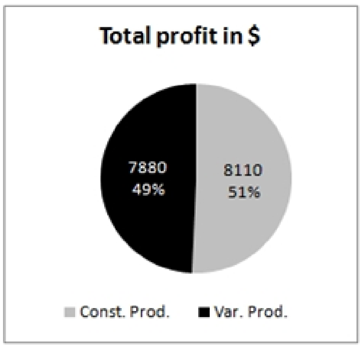


Fig. 3a and 3b: Production variation (case per week per employee) and Profit variation in dollar

6. Discussion

When we compare the 2 models together, we observe that introducing a variable productivity due to human factor leads to a completely different kind of production plan. The first model corresponds to a specialized production mode while the second corresponds rather to a balancing production mode.
In the initial constant productivity model, “easy” cases were assigned to the junior employee and complex cases to the expert and senior employees. This work distribution lies on a lowest cost logic and allows profit maximization. In the variable productivity model, assigning an important amount of the same cases to employees decreases their productivity. On one hand, the senior employee who has a low workload can take over a part of the easy cases assigned to the junior employee and a part of the complex cases assigned to the expert employee in the initial model. As the consequence, the simple and standard cases are now handled not exclusively by the junior employee but also by the senior employee and the workload tends to be more balanced between employees. On the other hand, the global workload increases in the variable productivity model with a reduction of the total profit because the cases could not be assigned only to lowest cost employees.

7. Conclusion

Production planning models that are today adapted to the service sector still keep some assumptions such as constant productivity rates that are inherited from industrial environments and machines. As a matter of fact in the service sector, humans play a primary role in the production instead of machines. Human productivity is not like machines productivity. It is more prone to variability due to stress, fatigue, boring task issues. Using standard production models present the risk that the human factor is not taken into account. For this reason, we have developed a production planning model that includes a human variable productivity formula. This formula retains different threshold levels

related to worker overload states. Each "plateau" in between the thresholds involves a productivity reduction.
To illustrate this model integrating the human variable productivity formula, we have developed a simple and fictitious case study. A professional service company (lawyer, auditing…) is handling cases of different difficulties (from simple to special cases) thanks to different statuses of employees (junior, senior and expert). With the model integrating the human variable productivity formula, we observe in the production plan a more balancing workload between employees. Besides, a same category of cases is handled by many employee statuses that improves polyvalence of the staff and allows employees to replace each other more easily. Employees execute a wider variety of tasks, are subject to less routine. Their job is more interesting and motivating. So with the new model, we are in a configuration where there is a better prevention of human risk such as saturation or burn-out. However dealing with human risk this way comes at a price.

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