Optimization model to design the crew training plan in an airline

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Abstract. Populations, flows and manpower hours are considered in the manpower planning problem. The objective is to project the structure of the categories with actual conditions that satisfy the operational needs. In this application, the populations are crew categories, the flows are employee hiring and transfers between categories depending on the career path, and manpower hours are the aircraft hours related to the crew need required to operate the aircrafts. The application uses transfers as integer decision variables and continuous decision variables to describe the slack in the manpower hours. The classic approach for this kind of problem is a probabilistic model like the Markov chain but this application uses a deterministic model to evaluate scenarios that don't depend on previous events giving the flexibility to create scenarios depending on different future possible environments. The use of the tool helped to reduce the evaluation time of a scenario from days to minutes and possible actions to reach the most efficient manpower hours.

Keywords: Operations Research, Airline applications, Optimization.

1 Introduction

1.1 Context

In Mexico, the air transport sector represents an important contribution to the country's economy; air transport is 3.5% of the Gross Domestic Product (GDP) in conjunction with tourism and the supply chain with which it collaborates. In 2019, growth in the sector was projected at 104% for the next 20 years. The projection was promising for this service sector, but market conditions can be modified from one year to another, as observed in 2020 when the industry faced a pandemic, Coronavirus Disease 2019 (COVID-19). The pandemic generated a contraction and uncertainty in the recovery of various markets, such as long and medium-range international trips, which led to repercussions on airlines and their supply chain. The suppliers of services and supplies of Turbosina, Planes, Lodging and Simulators suffered the most.

Pandemic uncertainty, amongst others, is generated by global political and economic situations. A clear example can be corroborated with the border closures implemented by countries such as Argentina, Peru, Canada, Japan and even countries of the European Union to prevent the spread of COVID-19 infections. The border closures banned travelers from other regions of the world, without defining an exact date for the reopening of the borders. Airlines were forced to consider definitive closures of routes and intermittent flight cancellations, that affect the diversity of services and the airline's image in the eyes of customers. Ultimately creating consumer uncertainty to carry out their trips and the industry supply chain.

This work focuses on the cabin personnel in the aircraft (pilots), a group of specialized workers essential for the operation of the airlines. Pilots are strictly managed not only by the airlines, but also by the local aeronautical authorities, where it is required to demonstrate the skills and technical knowledge of working conditions and the correct and safe operation of the aircraft.

For this reason, a series of very specific training is required, which entails extensive training times, as well as high costs due to the type of resources (simulators, instructors, etc.) that are required to carry out said training. The high cost forces airlines to rethink the training plan year after year: the airline must align resources to current conditions, seek alternatives to reduce costs related to them, and obtain feedback from the workforce to visualize the projected career plan.

2 The problem

The long-term strategic planning of human capital becomes a fundamental pillar in the implementation of the commercial strategy of companies and governments. If a company does not have the necessary resources for the training of the personnel it requires and the labor market does not have enough personnel; it will be difficult to achieve the objectives set in the desired time for the plan developed by the commercial or government strategy. Strategic planning should not be limited only to developing an ideal scenario that allows the desired objectives, but rather a detailed analysis should be carried out to reduce risks in its implementation (Ismail, Sulaiman, & Safa, 2019).

The uncertainty of the environment generates constant modifications of the commercial strategy of operators of the airline industry; in order to retain current customers in the face of growing competition. The modifications include increasing market share in those that suffered less damage, shrinking quickly in the face of a crisis, and reducing its fixed costs, for which a strategic planning of resources is required to achieve the objectives of said commercial strategy efficiently. The lack of communication between the commercial and operational strategy produces operational inefficiencies that

directly affect the viability of the commercial strategy. This affect revenues, net margins, profitability, market share, service level and image towards customers.
Long-term planning is carried out based on the hours to be operated depending on the number of aircraft held in each fleet. To carry out an operation, two positions are required, Captain and First Officer. Airplane hours are translated into position hours per fleet and personnel planning is carried out by category and fleet. Currently, the planning is carried out manually, with the vision and considerations that the planner has regarding the origin of people to fill future vacancies, using historical statistics of transfers.

The selection process can last between two to seven days, depending on the size and complexity of the fleet that the airline has at the time of the analysis, and the possible transfers and hires that are expected to meet the demand for position hours to operate in the desired monthly period. Other initial factors are considered in ideal conditions to evaluate movement for the fulfillment of the demand and the effect it entails for another group of crews intended to be carried each month: vacations, reservations, non-active duty personnel, daily productivity, resignations and retirements (Category and Fleet).

2.1 Approaches to address the problem

The Markov model is one of the most used in people planning systems since it uses the Markov chain theorem. The chain theorem is used for all dynamic systems with discrete stochastic processes which describes the evolution of the system over time. The Theory works by means of a set of random variables using the terminology of populations and flows, therefore this model is classified as predictive and is used in various problems. The Ondieng'a study (Ondieng'a, Mung'atu, & Orwa, 2016) uses this classic model for the Directorate of Rural Planning of the Ministry of Transfer and Planning of Kenya, using six grades or populations within the Directorate with a recruitment and transfers policy to meet the demand of said Directorate. Another example of the use of this predictive model is the Ezugwu study (Ezugwu & Ologun, 2017), applying it in the planning of the University staff of Uyo when determining the promotions, departures and recruitment of various categories and the future structure of the staff of the university in assessing whether current policies can be maintained or need to be modified to meet future demand.

The problem of long-term personnel planning can be described through populations and flows, so the recruitment and transfer policies of a company or government mostly describe the behavior of populations over time. The personnel movement policies allow us to know the demand for people in each of the groups, the Guerry study (Guerry, 2008) speaks of a "Push" model based on the profiles of personnel of the Belgian federal government, these profiles made it possible to generate homogeneous groups of people in internal flows and losses to model it with the Markov assumption, to find an optimal transfer and recruitment policy. The De Feyter study (De Feyter, 2007) adds a component to the "Push" model and converts it into a mixed "Pull & Push" model of transfers since it has the goodness of being able to balance the vacancies of each of the groups when pushing or pulling transfers anticipating a lack of staff in the various groups to be studied and with it being able to determine a recruitment policy that suits such transfers.

The education sector uses these types of models to determine the training capacity that has to be achieved to generate the necessary number of personnel with the projected growth, for example, (Marlin & Sohn, 2013) is used for the education sector in Afghanistan. Since due to the armed conflicts in that country the capacity to train people to be teachers was drastically reduced. For this case the entire programming and a network flow model was used, which allows to find weaknesses in the future development of the Afghan education system and find better alternatives that allow to meet the desired demand for teachers in the various regions of the country. In turn to make the appropriate decisions in the development of the education system by delivering a quality service.

Another example is used by (Ghoseiri & Ekhtiari, 2013) when using a stochastic model for developing a global criterion model limited by chance allowing to create restrictions and objectives randomly to reduce the number of iterations in the search for a solution.

A very particular example found in the literature, (Kaplan, Mongeon, & Ryan, 2014) applies the methodology of the Markov chain to estimate the probability that the players contribute during the development of the Hockey game to win it. This because in this sport when a player is penalized he leaves for a certain period of time and creates a lack of personnel in the game by generating a decrease in the probability of winning a game for the penalized team and increases the probability of winning for the opposing team.

The previous models focus only on recruitment or transfer policies without describing the operational problems involved in implementing such planning. For this reason, some researchers propose more realistic models when integrating additional problems to the solution such as the effectiveness of training, as an example (Chowdhury, Mangaraj, & Jomon, 2019) uses objective programming to operationally describe the impact of various assumptions in personnel planning. These types of models have been suggested not only for personnel planning but to balance between production, income, costs and demand (Sinha & Sen, 2011). So this type of models allows to find a balance between different factors that affect the problem and that have a different modeling to make a global solution.

Ernst et al. (2001) propose an integrated optimization model to solve both crew scheduling and crew rostering. The objective of this model is to minimize roundtrip costs, penalty costs, and fixed costs to employ a crew at each depot. This model has constraints to ensure that the number of roundtrips selected in a solution from a clique must not be more than the number of planned crew in a depot. Depots are places where crews may be allocated, may rest o may change shifts. The model was applied to three real problems from the Australian National Rail.

Azmat et al. (2004) proposed four mixed integer programming models to solve the workforce schedule problem for a single shift. The models include legal constraints and the minimum required workforce was guaranteed. The model generates a workforce schedule that minimizes and balances workload during a year. It considers weekly customer demand. Two scenarios to assign holidays were considered.

Rauf et. al. (2016) addressed the crew problem using time instead of money as the cost in an integer program. This is because time can be easily converted into money once it can be established how much money is being spent at any given time. The difficulty in obtaining financial data suggests another standard option.

Onifade et. al (2020) exposes the challenges facing the Nigerian national maritime sector, especially in the area of manpower training. The training of staff is very necessary for the effective performance of their duties. This is because the development and maintenance of the sector depend on the availability of the right workforce at the right time and place.

3 Proposed model

3.1 Sets

One of the most important sets of the model is the number of periods that will use to iterate. The time measurement of these time periods will be monthly since most of the data are monthly, there are *n* number of periods depending on the projection that you want to determine by the model, these periods will be grouped *T* in the set shown below. Using the newly created set it is desirable to determine a set which allows dividing the periods into years so that a set will be created which has A as its beginning a period I as long as the last period is not greater than the maximum period of the set T.

$T = \{0,1,2,3, \dots n\}$ (Period times)

$A = \{I + (12 * a), I + (12 * 1), \dots I + (12 * (n/12))\}$ (Beginning of year)

Because the model is described by means of populations and flows, it is necessary to define the characteristics or sets that classify the personnel in subgroups or categories (Populations). Our population are pilots who have the characteristic or ability to operate a team in a particular position that is described by a category. For this reason, the fleet that the company has must be described, creating a set called *FL* which will determine the types of aircraft that can be operated in this case. The fleet consists of 3 types of Airbus 220 and 380 aircraft, and Boeing 757, it is also required to create a set called P which will allow defining the positions for operating in said fleet, being the position of "CP" (Captain) and "FO" (First Officer) as observed in the set.

$FL = \{"220", "380", "757"\}$ (Fleet)

$P = \{"CP", "FO"\}$ (Positions)

To define the groups or categories of our population it is necessary to make a new set G which uses the sets described above ("FL" and "P") with the fleet being the main set and the position the subscript of the fleet to determine the possible categories as shown below.

$G = \{P_f\}\ f \in FL$ (Groups)

3.2 Parameters

Once the groups of our population were determined, the parameters that affect each subgroup were defined, such as the number of people who are not productive, for example personnel who are in Reserves, Office, Union, etc. An important set of parameters to consider is those that describe the actual operational limits such as training capacity, expected monthly productivity, average training time per fleet, etc. Finally, and most importantly for the model, it is proposed to parameterize the company's transfer and recruitment policy to allow for a sensitivity analysis to find the policies that best adapt to the future needs of the company.

The parameters described will allow us to model the operational and contractual constraints faced by the medium- and short-term planning for the implementation of a training plan, as well as the feasibility and requirement of future resources in the training to meet the projected demand.

$F(t)_j \quad \forall\, j \in G, t \in P$ (Out of Role)

$R(t)_j \quad \forall\, j \in G, t \in P$ (Reserves)

$O(t)_j \quad \forall\, j \in G, t \in P$ (Office)

$I(t)_j \quad \forall\, j \in G, t \in P$ (Incidents)

$J(t)_j \quad \forall\, j \in G, t \in P$ (Retirement)

$DE(t)_j \quad \forall\, j \in G, t \in P$ (Distribution of recurring workouts)

$DV(t)_j \quad \forall\, j \in G, t \in P$ (Vacation Distribution)

$P(t)_j \quad \forall\, j \in G, t \in P$ (Monthly Productivity)

$N(t)_j \quad \forall j \in G, t \in P$ (Crew needed per flight hour)

$B(t)_j \quad \forall j \in G, t \in P$ (Flight hours)

$DT(t)_{ij} \quad \forall i, j \in G, t \in P$ (Transfer Distribution)

$CA(t)_j \quad \forall j \in G, t \in P$ (Training Capacity)

$C(t)_{ij} \quad \forall i, j \in G, t \in P$ (Cost of transfer training)

$C(t)_{0j} \quad \forall j \in G, t \in P$ (Cost of onboarding training)

$TA_j \quad \forall j \in G$ (Training Time)

Finally, it is necessary to define some input parameters that allow delimiting the beginning and end of the projection such as the initial month and year, the number of periods to be projected and the initial plant of the model.

MI (Starting Month)

AI (Starting year)

NP (Number of Periods)

$Y(0)_i \forall j \in G$ (Starting Time)

3.3 Variables

Once these parameters have been defined, we have to determine our decision variables which the model will have to determine, being the transfers and incorporation of people in the work plant, that is why the variable X will be used which will have 2 subscripts being j e i which belong to the groups determined by G and describe the transfers from one group to another group in particular and a second variable $X0$ with subscript j which will describe the income to the company to a certain group in particular.

$X_{ij} \forall j, i \in G$ (Internal Transfers)

$X0_j \forall j \in G$ (Income)

Given our decision variables, we have to group these variables over time and, to or from a category since they will affect the amount of plant that we have over time, that is why we developed the variable $XT(t)_j$ with the subscript j which will group the transfers to the group j in the period t, being the same case of the variable $XF(t)_i$ with subscript i when describing the transfers from the group j in the period t as observed below.

$XT(t)_j = \sum_{i \in G} X(t)_{ij} + X0(\mathrm{t})_j \; \forall j \in G, t \in T$ (Transfers to group j)

$XF(t)_i = \sum_{j \in G} X(t)_{ij} \; \forall j \in G, t \in T$ (Transfers from group j)

Grouped such transfers we can calculate an important variable in this type of problems being the total plant of people in a category over time, this total plant will be described with the variable Y(t)g which takes the plant of the previous period and subtracts the transfers that leave that category in the current period and the retirements (J(t)) that must be granted, the transfers that began n periods in the past are added which is determined by the variable (Group training time g) said calculation will begin in period 1 since period 0 contains the initial plant of the model.

$Y(t)_g = Y(t-1)_g + XT\left(t - TA_g\right)_g - J(t)_g - XF(t)_g \; \forall g \in G, t \in T$ (Total Plant)

For some parameters described in the previous section it is required to use an annualized distribution to determine the number of people who will be on vacation or recurring training since the projection will depend on the plant at the end of the previous year. To determine the closure of the previous year we will use the set A granting the parameter I as the subtraction between 12 minus the initial month of the model.

$I = 12 - MI$ (Initial Set C)

$E(t)_j = DE(t)_j * Y(x)_j \; \forall j \in G, x \in C, t \in T$ (Recurring training people)

$V(t)_j = DV(t)_j * Y(x)_j \; \forall j \in G, x \in C, t \in T$ (People on holiday)

Once these variables are determined, we can determine our last variable, which is the YP(t)j production plant with subscript j which will allow us to describe later the restriction of the installed capacity of the category, for this we use the total Y(t)j plant and we will subtract the non-productive people who are people on holidays, reservations, out of role, incidents, recurring training, office and union.

$YP(t)_g = Y(t)_g - V(t) - F(t) - R(t) - O(t) - I(t) - E(t)$ (Production plant)

3.4 Objective function

It is proposed to minimize the cost of company training, since our main variable of interest are the internal flows and incorporations into the company that are represented by the variables $X(t)_{ij}$, $X(t)_{0j}$ and their respective costs (C_{ij} y C_{0j}), these variable has to be described in our objective function by means of the function Z que that is observed in Equation 1.

$$Z = \sum_t \sum_i \sum_j X(t)_{ij} * C_{ij} + \sum_t \sum_j X(t)_{0j} * C_{0j} \;\forall\, \mathrm{i}, j \in G \qquad (1)$$

3.5 Constraints

One of the main operational limitations is monthly training capacity per fleet, so the restriction (1) of the model that is described in Equation 2 is developed. The sum of all the transfers of both positions of the set P to a particular fleet of the set FL must not exceed the monthly capacity described by CA_f, for this we use the variable $XT(t)_{p_f}$ described in the variable section which describes the sum of all the transfers of the various subgroups to a particular subgroup, to end the restriction the sum of the transfers to the 2 positions of the fleet is made and this must not exceed the limit described by the monthly capacity.

$$\sum_{p \in P} XT(t)_{p_f} \le CA_f \;\; \forall f \in FL, t \in T \qquad (2)$$

It is proposed to describe the restriction (2) as the policy of transfers and recruitment by means of the probability of transfer to a particular category with respect to the total of transfers to said category as we can see in Equation 3, this formula is required to have the restriction (2) in a linear way as observed in Equation 4. Also it is proposed to feed a group of categories in particular by means of a distribution of transfers and recruitment in a time window defined by set A as observed in Equation 5 which allows to create the restriction (3).

$$\frac{X(t)_{ij}}{XT(t)_j} \le DT(t)_{ij} \;\forall j \in G, t \in P \qquad (3)$$

$$X(t)_{ij} - (XT(t)_j * DT(t)_{ij}) \le 0 \;\forall j \in G, t \in P \qquad (4)$$

$$\sum_{t \in A}^{t+12} X(t)_{0\ \mathrm{FO757}} \le \sum_{t \in A}^{t+12} X(t)_{\mathrm{FO220\ FO757}} \qquad (5)$$

The restriction (4) is the last and most important of all the restrictions since it allows us to define the minimum installed capacity that is required to operate the commercial plan as observed in Equation 6. This restriction multiplies the production plant $YP(t)_j$ by the desired monthly productivity of the group $P(t)_j$ obtaining the installed capacity to operate in a certain period and has to be greater than the position hours of the month by multiplying the airplane hours by the need for crew members.

$$YP(t)_j * P(t)_j \geq B(t)_j * N(t)_j \ \forall \ j \in G \tag{6}$$

4 Introduction to initial data

Information is recorded in various Excel spreadsheets which will allow users to enter the required parameters with different structures depending on the information to be processed. The first structure consists of a matrix of Year and category per month, this structure is described in Fig. 1 with the following tabs that define the number of non-productive people, distributions or need of crew members to operate one hour of airplane Need Crew, People in Office, People in Union, Distribution of holidays, People in Reservations, People in Incidents, Distribution of recurring training, People in Permits and Retired People.

Year	Category	1	2	3	4	5	6	7	8	9	10	11	12
1	CP380	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
1	FO380	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
1	CP757	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
1	FO757	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
1	CP220	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333
1	FO220	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333	0.08333

Fig. 1. First Parameter Structure by Period.

The Second structure is displayed in Fig. 2 being a table in which each row defines the parameter based on the Year, Month, Category or Fleet. The structure describes the parameters of airplane hours, training times, monthly productivity in the Commercial Plan, E Data and PDD Monthly tabs.

Year	Month	Category	PDD Monthly	Workdays	PPD
1.00	1.00	CP757	80.93	19.50	4.15
1.00	1.00	CP380	82.50	16.50	5.00
1.00	1.00	CP220	76.05	19.50	3.90
1.00	1.00	FO757	80.93	19.50	4.15
1.00	1.00	FO380	82.50	16.50	5.00
1.00	1.00	FO220	76.05	19.50	3.90
1.00	2.00	CP757	70.55	17.00	4.15
1.00	2.00	CP380	77.50	15.50	5.00
1.00	2.00	CP220	66.30	17.00	3.90
1.00	2.00	FO757	70.55	17.00	4.15
1.00	2.00	FO380	77.50	15.50	5.00
1.00	2.00	FO220	66.30	17.00	3.90

Fig. 2. Second Parameter Structure by Period.

5 Validation.

To carry out the validation of the model, the selection of a historical plan was required. This selection is based on a past commercial plan that is stable to capture the natural behavior of the system and isolating external factors that can divert or skew the validation of the same. That is why the 2019 commercial plan was chosen and only 25 periods of said plan were used for the projection generated by the model since after said periods there are external growth factors. This stability allowed us to focus the validation of the model on the natural outputs of the system and the natural behavior of the movements that allow it to stabilize the system.

5.1 Comparative analysis.

When executing the model, a feasible solution was found exploring 12, 972, 796 solutions in 10 minutes, this solution is evaluated in 2 sections. The first are the selected transfers as observed in Table 1 which contains the number of transfers per category in the evaluated period, the unit cost of each transfer, as well as the total cost of each of the categories and of the solution. The second are the slack in the position hours found in Table 2 which contains the of slack costs of the position hours. The solution has per fleet, a unit cost of the fleet position hour and the total cost per fleet and of the solution to analyze the behavior of it.

Table 1. Transfer Costs of the Model.

Fleet	Model	Unit Cost	Cost
CP380	65	$ 803	$ 52,169
FO380	160	$ 453	$ 72,462
CP757	129	$ 511	$ 65,920
FO757	151	$ 299	$ 45,096
CP220	90	$ 442	$ 39,808
FO220	121	$ 296	$ 35,807
TLT	716		$ 311,263

Table 2. Slack Costs of the position hours in the model.

Fleet	Model	Unit Cost	Cost
380	14,116	$ 2,540	$ 35,854,375
757	17,729	$ 750	$ 13,296,705
220	23,514	$ 495	$ 11,639,397
TLT	55,359		$ 60,790,477

The objective function has the tendency to solve the slack of the existing position hours since it represents 99% of the cost of the solution while the transfers represent only 1% as can be seen in the proportion of the cost in Tables 1 and 2. This behavior is desired since the objective of the model is to reduce the slack of the position hours that is generated from the selected transfers to meet the demand of the commercial plan, the model generated a solution of 716 transfers with 55,359 slack position hours and a cost of 61,101,739 Mexican pesos. The same evaluation was carried out in the model for the historical plan as shown in Table 3 and 4, in said evaluation we can observe that this solution carried out manually has 790 transfers, 170,979 slack position hours and a cost of 147,167,030 Mexican pesos.

Table 3. Cost of Transfers from the Historical Plan.

Fleet	Historic Plan	Unit Cost	Cost
CP380	70	$ 803	$ 56,182
FO380	182	$ 453	$ 82,426
CP757	168	$ 511	$ 85,849
FO757	258	$ 299	$ 77,052
CP220	0	$ 442	$ -
FO220	112	$ 296	$ 33,144
TLT	790		$ 334,653

Table 4. Slack costs of position hours from historical plan.

Fleet	Historic Plan	Unit Cost	Cost
380	26,185	$ 2,540	$ 66,509,432
757	33,920	$ 750	$ 25,440,271
220	110,874	$ 495	$ 54,882,675
TLT	170,979		$ 146,832,377

Both solutions were compared to identify the differences in the selection of transfers and the impact on the slack position hours. The solution generated by the model allowed a 68% reduction in the clearance of position hours mainly in the fleet 220, this can be seen in the transfers since transfers to the positions of the fleet 220 increased due to the feeding to the other fleets of these positions generating a total reduction in the amount of training of 9% representing 74 transfers in the period evaluated. These actions of the model generated savings of 58%, representing savings of 86,065,291 Mexican pesos.

6 Conclusions

One of the main restrictions limiting a training plan is the monthly ability to start training, so it is recommended to evaluate the independent increase of each fleet to invest resources with the aim of achieving the desired increase. The change of policy can benefit depending on the needs of the commercial plan, as we observed, the plan remains stable so a change of income policy or transfers does not work completely since it can increase operating costs, this type of strategy will work when there is an increase in hours to operate in a particular fleet. It is recommended to carry out a complementary sensitivity analysis to analyze the maximum benefits in each of the scenarios designing them to the limit and with this visualize their maximum effect for their subsequent combination and creation of the long-term operational strategy of the airline's crew department that allows to reduce the slack there are hours position of the commercial plan that is planned to operate for the commercial needs of the market. In conclusion, the proposed model gives the necessary flexibility to evaluate possible modifications in the policy of transfers and new revenues to the company, allowing to evaluate the installed training capacity, the new revenues that are required, as well as the future structure of the plant and, if necessary, adjust the resources, parameters or contractual rules that allow to satisfy the evaluated business plan.

1 References

1. Azmat, C.S., Hürlimann, T. & Widmer. M. (2004). Mixed Integer Programming to Schedule a Single-Shift Workforce under Annualized Hours. Annals of Operations Research, 128, 199–215
2. Chowdhury, A. R., Mangaraj, B. K., & Jomon, M. G. (2019). Optimizing Manpower Planning: A Goal Programming Approach. The Indian Journal of Industrial Relations, 55(2).
3. De Feyter, T. (2007). Modeling mixed push and pull promotion flows in Manpower Planning. Springer Science+Business Media, 155, 25-39.
4. Ernst, A., Jiang, H., Krishnamoorthy, M., Nott, H., & Sier, David. (2001). An Integrated Optimization Model for Train Crew Management. Annals OR. 108. 211-224.
5. Ezugwu, V., & Ologun, S. (2017). Markov Chain: A Predictive Model for Manpower Planning. Journal of Applied Sciences & Environmental Management, 21(3), 557-565.
6. Ghoseiri, K., & Ekhtiari, M. (2013). Multi-objective stochastic programming to solve manpower allocation problem. International Journal of Advanced Manufacturing Technology, 65, 183–196.
7. Guerry, M.-A. (2008). Profile-Based Puch models. Applied Stochastic Models in business and industry, 24, 13-20.
8. Ismail, R., Sulaiman, N., & Safa, M. (2019). Re-Aligning the needs of Manpower for the Vision 2020: The case of the Manufacturing Sector in Malaysia. International Journal of Bussiness and Management Science, 9(3), 407-423.
9. Kaplan, E. H., Mongeon, K., & Ryan, J. T. (2014). A Markov Model for Hockey: Manpower Differential and Win Probability Added. INFOR Journal, 52(2), 39-50.
10. Marlin, B., & Sohn, H.-S. (2013). Manpower modeling and sensitivity analysis for Afghan education policy. International Journal of Industrial Engineering, 20(3-4), 273-281.
11. Morakyo, K. O., & Oluwaseyi, J. A. (2020). Modelling the manpower planning of nigerian port operations. Journal of academic research in economics, 12(3), 494-508.
12. Murugan, R., & Elangovan, R. (2018). Optimal Recruitment Policy for Manpower Planning Using Equilibrium Distribution. Jornal of ultra-scientist of physical science, 30(3), 172-182.
13. Ondieng'a, P. N., Mung'atu, J., & Orwa, G. O. (2016). The application of Markov model in manpower systems. International journal of research in commerce & management, 7(9), 24-27.
14. Onifade, M. K., Oluwaseyi, J., & Oroye, O. (2020). Modelling The Manpower Planning Of Nigerian Port Operations. Journal Of Academic Research In Economics, 12(3), 494 - 508
15. Rauf, K., Nyor, N., Kanu, R. U., & Omolehin, J. O. (2016). An Airline Crew Scheduling for Optimality. International Journal of Mathematics and Computer Science, 11(2016), 2, 187-198.
16. Salam, R., & Sharma, A. (2014). Systems and method for manpower planning for operating vehicles such as airplanes. Patent nº US008650058. United States.
17. Sinha, B., & Sen, N. (2011). Goal Programming Approach to Tea Industry of Barak Valley of Assam. Applied Mathematical Sciences, 5(29), 1409 - 1419.