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An integrated model for multi-period fuel management and fire suppression preparedness planning in forests

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Abstract

Wildfires are of the forest-related disasters caused by inhumane factors. Spreading of these fires is due to the increase of the density of flammable plants. Two important approaches to prevent this occurrence are fuel treatment and fire suppression resources preparedness. In this paper, a mixed integer programming model is proposed based on the covering location and assignment problems which seeks fuel reduction over a multi period of time in a forest area, along with fire suppression resources preparedness and dispatch of firefighters in the last period. One of the forest areas in northern Iran was considered to fuel treatment and fire suppression resources preparedness and assuming the growth of vegetation species varies in different parts, the region is separated into distinct and discrete network points. Obtained results of the model solving show an increase in the vegetation cover volume and reduction of the risk of fire.
Keywords: Covering location problem, mixed integer programming, wildfires, fuel treatment, suppression resources.

1- Introduction

Natural disasters such as earthquakes, droughts, wildfires, floods and storms from distant past have been an integral part of human life. Meanwhile, fire is an undeniable component of forest ecosystems that can be a serious threat to human life, natural resources, the environment and the assets (Martell, 2011). In Iran, each year, there are many small and large fires, especially in the north and west forests, which have both natural and human causes. The change in the climate of the planet and the increase in the temperature that occurred in the past years have increased the number and severity of these wild fires. Following this, the activities of firefighting centers have grown considerably. Increasing the height and density of flammable plants, in a forest cover, is one of the main reasons for increasing the rate of start and spread of wildfires in different regions. The actions of fire centers and environmental protection units are classified in terms of reaction time in three phases: 1) Pre-fire measures, including prediction, prevention and provision of essential equipment, 2) During the fire measures, including dispatch of firefighters, rescuing people and assets, suppression of fire and preventing it from spreading, 3) Post-fire measures, including site scene revision to maximize rescue operations, cleaning up the location of hazardous waste, estimating of damages and detriments caused by fire.

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Wildfire management involves a combination of complex activities and processes, such as fuel treatment, fire forecasting, precise location of fire detection, prevention of fire spread and suppression preparedness (Rachmawati et al. 2015)

Since the fire prevention and suppression preparedness planning to prevent it from spreading is much more effective than suppression of spreading and operations after the occurrence of the fire, so among the above-mentioned operations fuel treatment and fuel reduction are of particular importance and priority over other activities. The fuel treatment is referred to the change in volume and structure of flammable plants in a forest area, which can be in either one of the following two forms, or a combination of the two: Deliberate burning of weeds, dry and flammable plants, shortening and pruning, and fuel reduction (Finney, 2001). The goal of all preventive measures is to reduce the occurrence and to reduce the intensity of the fire as well as to speed the fire detection (Minas et al. 2014). In general, covering location problems are divided into several categories according to the type of target function and the nature of the problem data: set covering location problem, partial covering location problem, back up covering location problem, and fuzzy covering location problem. The problem presented in this paper is a partial covering location problem in the field of allocation and assignment, since the aim of the model is to maximize the coverage of different forest areas during the fire, with regard to the budget. The aim of this study is to achieve optimal decisions in a multi period fuel treatment and to allocate of fire suppression resources in the last period, taking into account the allocated budget. The "Toskistan" region of Golestan province has been considered as the area for the case study, and was divided into distinct and discrete network points for deciding to fuel treatment and resources preparedness assuming the growth of plant species varies in different parts of the region. This paper is organized as follows: Section two, reviews the literature and previous studies. In section three, definition of sets, parameters, variables, and problem modeling will be addressed. In section four, a case study is presented in a region of Northern Iran forests. In section five, the problem is solved. Section six is devoted to analyzing sensitivities and numerical studies. Finally, the last section presents the conclusion and suggestions for future studies.

2- Literature review

The research on fire prevention problems can be categorized in four areas: 1) The prediction of the occurrence of a fire and the conduct of fire prevention, which fuel treatment is considered to be one of these operations, 2) Asset protection, 3) Emergency evacuation and 4) Suppression of spreading. In this regard, Hoff et al. (2005) presented a linear programming model for reducing the speed of the arrival of a progressive fire to high potential areas. Reinhart et al. (2008) have proposed a mixed planning model aimed at finding the best places to carry out preventive action on fuel treatment and fire control of the future. Wei et al. (2012) formulated the implementation of fuel treatment with regard to the potential of each area to start a fire and according to the propagation time parameter. An integrated mixed integer programming model has been presented in Minas et al. (2015) to find optimal points for preventive action of fuel treatment and dispatch of firefighters. Minas et al. (2014) presented a multi period optimization model for fuel treatment to reduce the effects of forest fires. Also, a model with two objective functions was proposed by Shahparvari et al. (2015) to maximize the rescue of people after a fire and minimize the cost of using rescue vehicles. Minas et al. (2016) presented an integer programming model to maximize the collection of wood and waste products in areas with different plants in deliberate fires. Merker et al. (2008) have investigated the equilibrium between fire prevention and suppression of spreading the fire with the detriments caused by the fire. They analyzed the impact of each measure on fire behavior. In that study, the idea of multi-period fuel treatment model for fire prevention and suppression of spreading has been discussed. In spite of the fuel treatment measures, the important role of other q1 of firefighting centers, such as fire suppression resources should not be neglected. In fact, fuel treatment and fire suppression resources and firefighters kiosks are interacting with each other in order to control the fire, so they can't be accounted individually. By integrating the multi-period approach by how to use fuel treatment and fire suppression resources, the best decision can be made on this case. Hence, in the present paper, with regard to the existing research gap, a multi-period integrated optimization model is proposed for fuel treatment and the fire suppression resources.

3- Problem formulation

To formulate the model in this paper, we first consider some assumptions: the areas and the forests are assumed that have spread uniformly in square-shaped cells. Fire suppression sources refer to the resources that we need to prevent fire spreading. It can include the number of firefighters, the number of capsules and fire extinguisher tanks, or at large scale, the number of complete set of listed items wholesale. In the set of cells in vicinity of one cell, the cell itself is a neighbor cell (with a neighborhood radius of zero).

3-1- Indices and sets

i is the indicator of cell count (set of fire spots, where they are candidates for the implementation of fuel treatment); j is the indicator of cell count (a set of locations that have the potential of firefighter activities and fire suppression resources); t is the indicator of the time period, a subset of T, which is the index of the last period of fuel treatment and t_p is the last period that wildfire accrues at the end of mentioned period.

3-2- Parameters

If the j^{th} cell is placed in the vicinity of a zero radius or a cell from i^{th} cell, $a_{ij}=1$, otherwise $a_{ij}=0;$ If the j^{th} cell is placed in the vicinity of a zero radius or one or two cells from i^{th} cell, $b_{ij}=1$, and otherwise $b_{ij}=0$. wl_i is the average height of i^{th} cell plants in the first period; pr is the rate of plant height reduction after a fuel treatment in a period; c_{ij} is the cost of deploying and using each of firefighters in j_{th} cell; $cy_{i,t}$ is the cost of fuel treatment on i^{th} cell during t^{th} period; b_t is the total available budget for the use of firefighters and their fire suppression resources; by_t is the total budget available for fuel treatment in the t^{th} period; ru_i is the number of firefighters needed to suppress the fire in i^{th} cell, which in this cell the fuel treatment has not been performed in any prior period; ry_i is the number of firefighters needed to suppress the fire in i^{th} cell, which in this cell the fuel treatment has been carried out at least in one of the prior periods. M is the maximum number of firefighters that can be allocated in a cell.

3-3- Variables

$w_{i,t}$ is the average height of plants of i^{th} cells in n period $t;$ X_j is the number of firefighters allocated to the j^{th} cell; $y_{i,t}$ is the zero and one decision variable which indicates that if in i^{th} cell during t^{th} period the fuel treatment is carried out; Z_i is the zero and one decision variable which gets the value of one if the fuel treatment is carried out in i^{th} cell period t; ZU_i is the zero and one decision variable which indicates that if i^{th} cell, in which the fuel treatment has not been performed in any prior period, is suppressible by firefighters; ZY_i is the zero and one decision variable that indicates if i^{th} cell, in which the fuel treatment has been performed in at least one of the prior periods, is suppressible by firefighters; O_i is the zero and one decision variable which indicates if i^{th} cell has been under fuel treatment at least during one period; Q_i is a decision variable that is the product of the two variables $w_{i,tp}$ and Z_i, and indicating how much of the i^{th} cell's fuel treatment in the last period is suppressible by firefighters (defined for linearization of the model); $L_{i,j}$ is a variable that is the product of two variables X_j and Y_i used for linearization of the model.

$$\max Ft = \sum_{i \in I} Q_i \tag{1}$$

Subject to:

$$\sum_J (L_{i,j} * b_{i,j}) \geq ry_i * ZY_i \qquad \forall i \in I \tag{2}$$

$$\sum_J (X_j * a_{i,j} - L_{i,j} * a_{i,j}) \geq ru_i * ZU_i \qquad \forall i \in I \tag{3}$$

$$ZY_i \leq O_i \qquad \forall i \in I \tag{4}$$

$$Z_i \leq ZU_i + ZY_i \qquad \forall i \in I \tag{5}$$

$$\sum_J cx_j * X_j \leq bx \tag{6}$$

$$\sum_I cy_{i,t} * Y_{i,t} \le by_t \qquad t \in T \qquad (7)$$

$$X_j \le m \qquad \forall j \in J \qquad (8)$$

$$W_{i,t} = w1_i + t - pr * (\sum_T Y_{i,t}) \qquad \forall i \in I \quad , \quad t \in T \qquad (9)$$

$$L_{i,j} \le X_J \qquad \forall i \in I \quad , \quad \forall j \in J \qquad (10)$$

$$L_{i,j} \le M * O_i \qquad \forall i \in I \quad , \quad \forall j \in J \qquad (11)$$

$$L_{i,j} \ge X_j - M * (1 - O_i) \qquad \forall i \in I \quad , \quad \forall j \in J \qquad (12)$$

$$\sum_T Y_{i,t} \le M * O_i \qquad \forall i \in I \qquad (13)$$

$$\sum_T Y_{i,t} \le O_i / M \qquad \forall i \in I \qquad (14)$$

$$Q_i \le M * Z_i \qquad \forall i \in I \qquad (15)$$

$$Q_i \le W_{i,tp} \qquad \forall i \in I \quad , \quad \forall tp \in T \qquad (16)$$

$$Q_i \ge W_{i,tp} - M(1 - Z_i) \qquad \forall i \in I \quad , \quad \forall tp \in T \qquad (17)$$

$$Y_{i,t}, Z_i, ZY_i, ZU_i \in \{0,1\} \qquad \forall i \in I \quad , \quad t \in T \qquad (18)$$

$$X_j \in INT \;,\; L_{i,j} \in INT \;,\; W_{i,t} \ge 0 \;,\; Q_i \ge 0 \qquad \forall j \in J \quad , \quad \forall j \in J \quad , \quad t \in T \qquad (19)$$

3-4- Integrated model

The objective function of the above model (1) maximizes the total volume of plants that can be covered by firefighters and their fire can be suppressed. Equation (2) states that if the sum of firefighters from the neighboring cells to suppress the fire is larger or equal to the number of needed firefighters in the cell, so the cell is covered. Equation (3) expresses the same limitation condition for cells that have not been exposed to any fuel treatment in any periods. Equation (4) ensures that the cells that their covering or non-covering conditions are considered as modified cells, for sure it has been under fuel treatment at least once in one of the periods. Equation (5) indicates that the covered cell is one of the cells that have not been or have been covered by the fuel treatment. Equations (6) and (7) are the model budget constraints. Equations (8) is considered for the number of firefighters and equation (9) is considered for the plant height level of each cell. Equations (10) to (12) are used for linearization of the problem model. Equations (13) and (14) guarantee that if i^{th} cell has undergone fuel treatment at least once in one of the periods, Q_i gets the value of one, otherwise zero. Equations (15) to (17) are used for linearization of the model and equations (18) and (19) define type of variables.

4- Case study

Iran has forest vegetation in the northern and western parts of the country and because of the warm and dry weather in many areas of its northeastern and southwestern, there are many wildfires each year in these areas. The increase in temperature during recent years, especially in the first half of the year, has caused a significant increase in the occurrence of such fires, such that more than five hectares of forest and pastures in the Basht in Gachsaran, Kohkiluyeh and Boyerahmad province, burned after continues fires in May and June of 2017.

Also in May of 2017, the burning of the Harderij forests in the province of Ilam was so severe that the county seat asked for help from ordinary people in firefighting. As mentioned in the introduction, a case study of this article is one of the northeastern forests of Iran called Kaboodul Forest, located in Tuskestan region of Golestan province. As seen in figure 1 the forest is located in the south of Kowsar Dam, and southwest of Gorgan. In figure 1 (b), the Tuskestan region and the major part of the Kaboodul vegetation are specified on the right side of the map. Each of the square divisions represents a cell, each cell can be different from the others in terms of the height of the initial vegetation, the water present in the soil, and other factors affecting the growth of the plants, and the conditions such as plant management restrictions, the value of the type of covering and the fire suppression resources and the firefighters' activity. In figure 1b, for the implementation of the model and solving the multi-period integrated optimization problem for preventive maintenance of fuel treatment and the deployment of fire suppression resources, one part of the Kaboodul forest center, including 100 cells, has been selected. These points are selected for implementation of the model and its validation, investigation of the results, and analysis of the sensitivities. They are specified with distinct color and are identified as a ten in ten landscape from other forest areas.

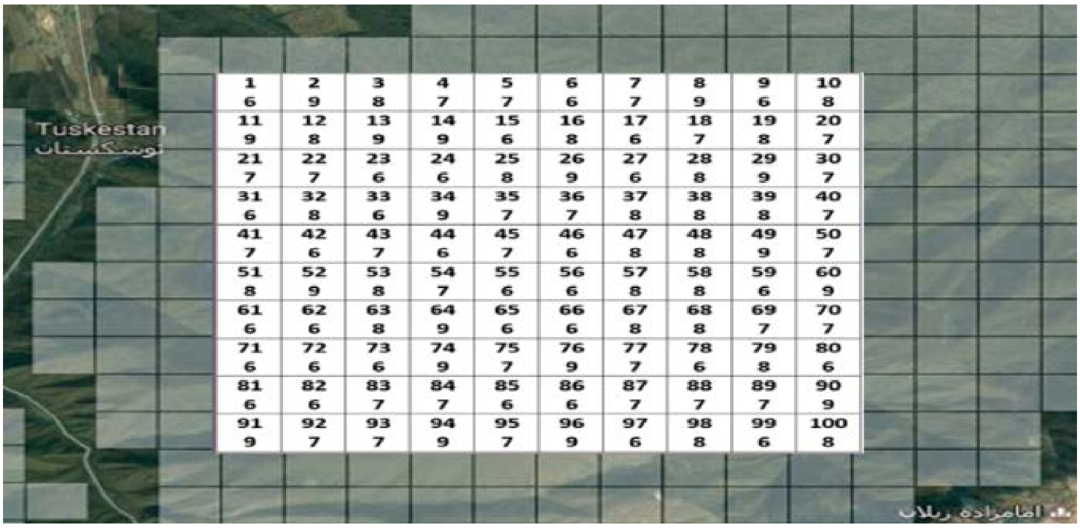


Fig 1. (a) Aerial map of Kaboodul forest in Tuskestan region of Golestan province. (b) Selection of 100 cells and distinguishing them as studied points from the Kaboodul forest and mentioning the initial height of the plants of each cell during the period t=0

5- Results

The data on the model parameters and the data used as assumption and primary to validate and solve the model are presented in table 1.

Table1. The value of the model parameters

Parameter	**Value**
$\|I\|$	100 cells (as 10 * 10)
$\|J\|$	Related to the same set of 100 cells of *i*
$\|T\|$	4 periods
tp	4th period
$a_{i,j}$	Cells with distances smaller or equal to 1 from the target cell
$b_{i,j}$	Cells with distances smaller or equal to 2 from the target cell
wl_i	A random integer between 6 and 9 (the uniform distribution function) on a scale of height
pr	Integer and constant of 3 units, to reduce height for each fuel treatment
cx_j	40,000 cost unit
$cy_{i,t}$	5,000 cost unit
bx	1,000,000 cost unit
by_t	50,000 cost unit
ru_i	A random integer between 2 and 6 (the uniform distribution function) of firefighters
ry_i	2 firefighters
M	25 firefighters

CN=1 W_0=7	2 10	3 9	4 8	5 8	6 7	7 8	8 10	9 7	10 9
11 10	12 9	13 10	14 10	15 7	16 9	17 7	18 8	19 9	20 8
21 8	22 8	23 7	24 7	25 9	26 10	27 ✂ 4	28 9	29 10	30 8
31 ✂ 4	32 9	33 7	34 10	35 8	36 8	37 9	38 ✂ 6	39 ✂ 6	40 8
41 8	42 7	43 ✂ 5	44 ✂ 4	45 8	46 7	47 9	48 9	49 10	50 8
51 9	52 10	53 9	54 8	55 7	56 7	57 9	58 9	59 7	60 10
61 7	62 7	63 9	64 10	65 7	66 7	67 9	68 9	69 8	70 9
71 7	72 7	73 7	74 10	75 8	76 10	77 8	78 7	79 9	80 7
81 ✂ 4	82 7	83 8	84 8	85 7	86 ✂ 4	87 8	88 8	89 8	90 10
91 10	92 8	93 ✂ 5	94 10	95 8	96 10	97 7	98 9	99 ✂ 4	100 9

CN: cells Number, W_0: initial height in first period, ✂: Implementation of Fuel Treatments

Fig 2 (a). Cells status in period t = 1

CN=1 R=2 W=10	2 2 13	3 4 12	4 4 11	5 2 (III) 8	6 3 10	7 3 11	8 3 13	9 2 10	10 2 (IV) 9
11 2 P=(II) 10	12 2 12	13 3 13	14 3 13	15 3 10	16 2(IV) 9	17 2 10	18 3 11	19 2 12	20 2 (II) 8
21 2 11	22 3 11	23 3 10	24 2 10	25 2 12	26 4 13	27 2 (I) 7	28 2 12	29 2 (III) 10	30 2 (IV) 8
31 2 (I) 7	32 2 (II) 9	33 2 (II) 7	34 2 (III) 10	35 2 (IV) 8	36 4 12	37 2 12	38 2 (I) 9	39 2 (I) 9	40 2 (IV) 8
41 2 (IV) 8	42 2 (IV) 7	43 2 (I) 8	44 2 (I) 7	45 2 (II) 8	46 3 10	47 3 12	48 2 12	49 3 13	50 2 (III) 8
51 2 (II) 9	52 2 13	53 2 12	54 4 11	55 2 10	56 5 10	57 5 12	58 2 12	59 3 10	60 2 (IV) 10
61 2 (III) 7	62 2 (IV) 7	63 2 (III) 9	64 2 13	65 2 10	66 2 10	67 4 12	68 2 12	69 5 11	70 2 12
71 2 (III) 7	72 5 10	73 4 10	74 4 13	75 2 11	76 4 13	77 4 11	78 6 10	79 2 12	80 2 10
81 2 (I) 7	82 2 10	83 2 11	84 2 11	85 2 (III) 7	86 2 (I) 7	87 2 11	88 2 11	89 2 (III) 8	90 3 13
91 2 (II) 10	92 3 11	93 2 (I) 8	94 4 13	95 2 (II) 8	96 2 (II) 9	97 2 (II) 7	98 2 (III) 9	99 2 (I) 7	100 2 (IV) 9

R: Suppression Resources Required, W:height after 4 periods, P: number of treated periods,

Fig 2 (b). Cells status in period t = 4

As was seen in section four, in figure 1.b, the cells are numbered and the height of the vegetation of each cell is determined at the period t = 0. The decision to modify based on considerations such as initial height and flammable volume after growth, will be examined in this section. As shown in figure 2.a, in the first period, with respect to plant growth and fuel treatment, the plant height was determined at period t = 1. Over time, the second, third, and fourth periods (only the results of the fourth period are shown for brevity) the final heights of vegetation after growth and corrections, and the number of firefighters needed in each cell to suppress the fire as well as the number of the period in which the cell has been modified are shown in figure 2 b.

CN= 1 R= 2 W= 10	2 2 13	3 4 12	4 ⍓ 4 11 1	5 2 (III) 8	6 3 10	7 3 11	8 3 13	9 2 10	10 2 (IV) 9
11 2 P=(II) 10	12 ⍓ 2 12 2	13 ⍓ 3 13 1	14 3 13	15 ⍓ 3 10 2	16 2 (IV) 9	17 ⍓ 2 10 1	18 ⍓ 3 11 2	19 2 12	20 2 (II) 8
21 2 11	22 3 11	23 3 10	24 2 10	25 2 12	26 4 13	27 2 (I) 7	28 2 12	29 2 (III) 10	30 2 (IV) 8
31 2 (I) 7	32 2 (II) 9	33 2 (II) 7	34 2 (III) 10	35 2 (IV) 8	36 4 12	37 2 12	38 2 (I) 9	39 2 (I) 9	40 2 (IV) 8
41 2 (IV) 8	42 2 (IV) 7	43 2 (I) 8	44 2 (I) 7	45 2 (II) 8	46 3 10	47 3 12	48 ⍓ 2 12 2	49 3 13	50 2 (III) 8
51 2 (II) 9	52 2 13	53 2 12	54 4 11	55 2 10	56 5 10	57 5 12	58 ⍓ 2 12 1	59 3 10	60 2 (IV) 10
61 2 (III) 7	62 2 (IV) 7	63 ⍓ 2 (III) 9 2	64 2 13	65 ⍓ 2 10 2	66 2 10	67 ⍓ 4 12 2	68 2 12	69 5 11	70 2 12
71 2 (III) 7	72 5 10	73 4 10	74 4 13	75 2 11	76⍓ 4 13 1	77 4 11	78 ⍓ 6 10 1	79 ⍓ 2 12 2	80 2 10
81 2 (I) 7	82 2 10	83 ⍓ 2 11 3	84 2 11	85 2 (III) 7	86 2 (I) 7	87 2 11	88 2 11	89 2 (III) 8	90 3 13
91 2 (II) 10	92 3 11	93 2 (I) 8	94 4 13	95 2 (II) 8	96 2 (II) 9	97 2 (II) 7	98 2 (III) 9	99 2 (I) 7	100 2 (IV) 9

CN: cells Number, R: Suppression Resources Required, W:height after 4 periods, ⍓ : allocated Suppression Resources, P: number of treated periods

Fig 3. Deployment of firefighters and covered cells and burned cells

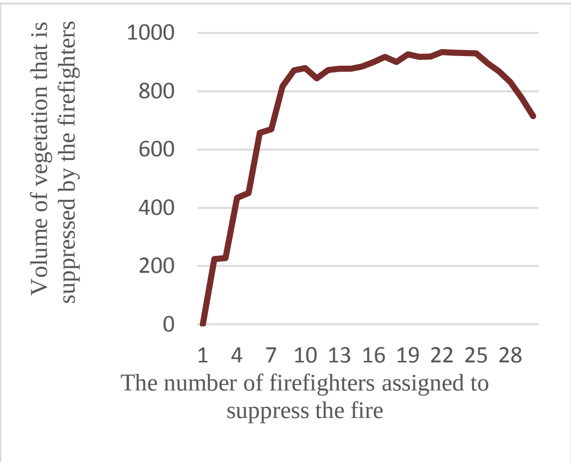
After four periods and the completion of the fuel treatment, as in the assumptions, a fire occurs and the model specifies the optimum points for deploying the firefighters, so that the most possible suppression of the fire may occur. The results obtained from solving the above model represent the coverage of 930 units of forest plants investigated, which is shown in figure 3.

6- Discussion

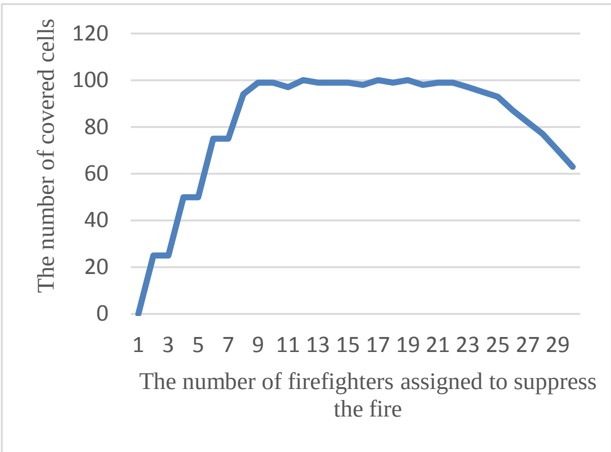
In this section, some sensitivity analyzes of the model are presented and in the first part, the model's innovations are examined comparing to the previous articles. In the second part, by imposing limitations such as the construction of fire control bases outside the forest, as well as considering the strategic points, the model is verified.

6-1- Comparison with classical model

The value of the objective function in the case of non-integration of the fuel treatment model with the deploy of firefighters model and considering each one separately is less than the objective function of the integrated model, which also demonstrates the necessity of using the idea of this article as well. Fig. 4.a shows the diagram of the number of covered cells for allocating different budgets from the total constant budget to fuel treatment and the number of firefighters, which has an approximation consistency in its initial and final trends with the diagram of changes in the objective function. As shown in Fig. 4.b, in three modes of deploying of twelve, seventeen and nineteen firefighters, whose target function has the values of 873, 918 and 927, the fire is suppressed in every 100 cells, while in the optimal mode of allocation of funds the target function is 935 units, and twenty-two firefighters are deployed, and fire is not suppressed in every 100 cells. The important point is that in cases where the firefighting budget is between nine and nineteen, although the number of firefighters has increased to cover between ninety seven to hundreds of cells, but as the funding for fuel treatment is still high, by suppression of the covering of all 100 cells also the value of the target function is less than the optimal mode.



(a)



(b)

Fig 4. a) Target Function diagram (total volume of vegetation that is suppressed by the firefighters). b) Diagram of the number of covered cells for allocating different budgets from the total budget to the fuel treatment and the number of firefighters.

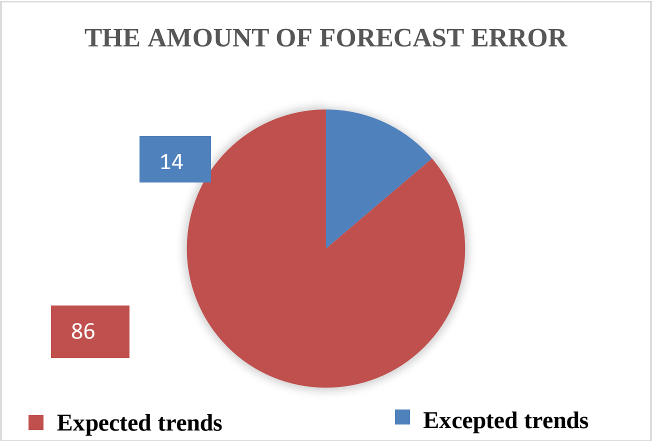


Fig 5. Circular diagram showing the compliance rate of the target function changes with the predicted trend of the model

With the changes of the assigned budget to the firefighters and the number of modified cells, the value of the target function is considered in the thirty different states in figure 5. Between these thirties, there are twenty nine variations in the trend of the objective function, from the one to the optimal point, namely the allocation of twenty two firefighters, there are four exceptions (880 to 845, 878 to 878, 918 to 900, 927 to 928), while, after the optimal point to the assignment of thirty firefighters, all trends are decreasing and there are no exceptional trends. The ratio of these four modes to the twenty nine existing trends is shown in the circle diagram of the predicted error rate in figure 5.

6-2- Computational testing

Figure 6 shows that when two cells of 26 and 78 (which are not addressed in solving the main problem in any period and eventually the fire is not suppressed in these two cells) are considered as strategic points, both fuel treatment is carried out on them and the fire in these two cells is suppressed. For this purpose, twelve firefighters are considered to be needed to suppress in these two cells. As shown in figure 6, the vegetation volume of these two cells is assumed to be thirty units. Thus, out of twenty five firefighters, there are 18 firefighters stationed in these two or one or two-cell distant neighborhoods (due to fuel treatment on these two cells), and only seven firefighters have been deployed in other cells.

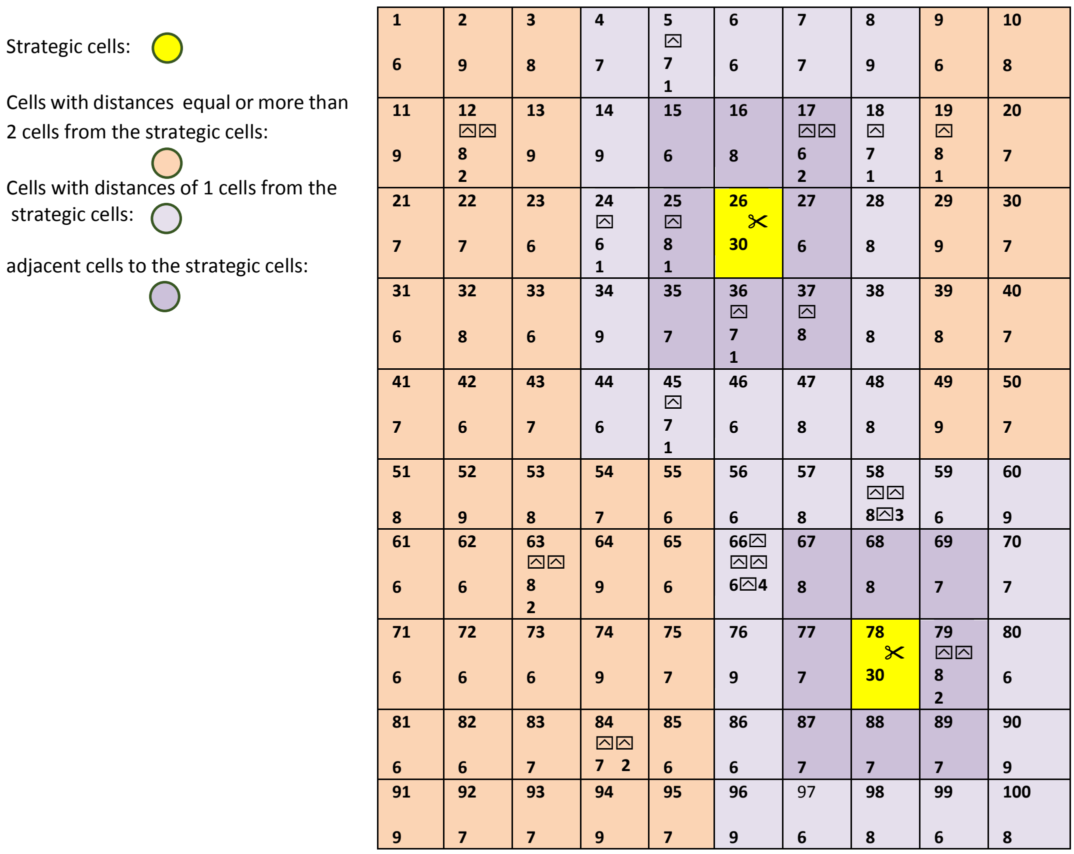


Fig 6- Deployment of firefighters around two strategic locations (Cells 26 and 78) and performing fuel treatment

Figure 7 allows the deployment of firefighters and fire suppression resources only at the northwest corner, namely cell 1, and the southeastern corner, namely cell one hundred. Thus, in the event of a fire from twenty five firefighters, only four firefighters are deployed in cell 1 and six firefighters are in cell 100, and only eighteen of the 100 cells are covered by fire suppression, with nine cells in the northwestern neighborhood of the forest and nine cells in the southwestern neighborhood of the forest, which assigns an target function equivalent to 176 units to itself. The useless of fifteen other firefighters, as well as the burning of eighty-two cells out of one hundred cells, shows that in the case of this study, like other covering models of emergency evacuations, the concept of the time of rescue is considered in the definition of neighbors and the nature of problem modeling and the distance of the corners with the inland areas of the forest caused burning of eighty-two cells until fifteen other firefighters arrived. Once again, the above sensitivity analysis was considered by a 100-fold increase in the firefighting budget, and the results from solving it were obtained as shown in figure 7, indicating that the increase in budget had no effect on the change in the target function and the number of rescued cells.

Covered cells:

uncovered cells:

1 6 x=4	2 9	3 8	4 7	5 7	6 6	7 7	8 9	9 6	10 8
11 9	12 8	13 9	14 9	15 6	16 8	17 6	18 7	19 8	20 7
21 7	22 7	23 6	24 6	25 8	26 9	27 6	28 8	29 9	30 7
31 6	32 8	33 6	34 9	35 7	36 7	37 8	38 8	39 8	40 7
41 7	42 6	43 7	44 6	45 7	46 6	47 8	48 8	49 9	50 7
51 8	52 9	53 8	54 7	55 6	56 6	57 8	58 8	59 6	60 9
61 6	62 6	63 8	64 9	65 6	66 6	67 8	68 8	69 7	70 7
71 6	72 6	73 6	74 9	75 7	76 9	77 7	78 6	79 8	80 6
81 6	82 6	83 7	84 7	85 6	86 6	87 7	88 7	89 7	90 9
91 9	92 7	93 7	94 9	95 7	96 9	97 6	98 8	99 6	100 8 x=6

Figure 7- The deployment of firefighters in the northwestern and southeastern points of the forest and the lack of fire suppression resources inside the forest

7- Conclusion

Preventive fuel treatment and firefighting and fire suppression resources are two important activities in the field of combating wildfires and reducing their detriments and losses, which the first is in the pre-occurrence phase and the second is in the phase of the occurrence. Taking into account the time horizons and the implementation of multi-period fuel treatment with the idea of plant growth and combining fuel treatment operations with firefighting operations and providing an integrated solution model for solving this problem with considering the budget constraints, is the goal of this study which was described in the modeling and problem solving sections. Finally, by providing an integrated mathematical model for scheduling to determine the optimal points for each period requiring fuel treatment and allocating fire suppression resources to the most appropriate points in the last period, this paper investigates on the maximization of the volume of the covered plants to suppress fire and reduce the risk of a wildfire in the studied forest area. Considering stochastic nature of the problem can be a future direction of this study.

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