Mathematical Modelling and Performance prediction of Hydraulically Driven Water Monitor Trailer for Fire Fighting using ANN simulation

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Abstract

It is difficult to control fire by impinging water or foam from a distance. The effectiveness is reduced due to high evaporation rate. Thus requires more water and more time for extinguishing the fire. Water or foam monitor cannot be taken closer to fire due to intense heat and the possibility of explosion. A remote controlled vehicle can bring the monitor closer to the fire and improve the effectiveness of fire fighting. Electrical or electronic devices are very sensitive to high temperatures and the batteries used can explode. Under such circumstances electronically controlled and battery operated vehicle is impractical. It is required to develope a hydraulically driven vehicle motion by using pressurized water flow through fire fighting hose and it is named as Hydraulically driven water monitor trailer (HDWMT) This paper describes mathematical modelling for HDWMT for the two dependent indices i.e., tractive force and velocity of trailer.

Keywords: Fire fighting ; water monitor trailer ; Tractive force, Mathematical modelling, ANN

1. Introduction

Fire protection requires the delivery of necessary material at right time, in adequate quantity and in proper form at the desired place to accomplish the desired results. Generally, this rule is satisfied to large extent in case of minor fire as water monitor can be taken nearer to the fire place. However, when the size and intensity of the fire is massive, the water monitor or any other extinguishing device cannot be brought closer to the fire and firemen are forced to operate it from fairly long distance. This cause difficulty in hitting the target precisely while many times it is impossible to reach the spot, too.(Nikitin, Golubin, Belov and Andrianov, 2019) When water is sprayed from a long distance, to extinguish a massive blaze, the problem of evaporation hits rescue operation. Evaporation of water in a certain amount can be happened. This reduces the quantity of water being used for extinguishing fire. Because of this, fire tenders require more energy besides the loss of scarcely available water resource (Li- Sali, et. al., 2023). Eventually, the fire takes a long time to be brought under control. Not only the requirement of water goes up due to evaporation but also the whole exercise consumes lot of man power, and other resources without yielding the desired results. If water can be spread form a closer point, even massive fires can be fought efficiently and

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economically. This can be achieved by taking the water monitor closer to the fire spot (Manual of fire fighting book 7, 1987). Thereby proper targeting, less evaporation, faster quenching and reduction in losses caused by the fire are possible. Reducing the distance by manually-driven trailer is impossible due to possibility of burning causalities. Hence, Remote-controlled trailers, which can be taken closer to the fireplace, are required. However, drives and components used in a remote-controlled trailer need to be chosen carefully. Electric motors, switches, electronic circuitry, battery packs, etc. cannot work at high temperature, even after sufficient shielding. Therefore, there is need to develop a system which can prevent these drives and components from catching fire. An innovative concept trailer has been designed for carrying the water monitor closer to fire spot using the hose as a driving unit. The hose drive converts hydraulic energy into mechanical advantage in the form of trailer motion. This energy output is high and adequate to drive a system on any surface. The flexible hose has a tendency of straightening under high pressure. This straightening phenomenon of the hose at higher water pressure can be utilized for pushing the water monitor trailer with the help of suitable mechanism. The hose can sustain high temperature for a longer duration as the water flows through it (larin-morozov et.al., 2019). Therefore, it is proposed to device a hydraulically-driven trailer using the behavioural response of hose. Water and water pumps are available along with the water tender. The device does not need a continuous supply of water and hence, it does not consume water for driving. It requires water equivalent to the volume of water that could be stored in the full length of hose, which is very less as compared to the water generally required for fire extinguishing. This system consists three subsystems, energy unit and mechanical-power transmission system and trailer assembly. The energy unit comprises a pump, a novel mechanism consisting of roller pair assembly and hose (Kadu and Bhende 2010). The hose size may vary as per availability and application. Generally, hose of diameter 63 mm and 3.2 mm thickness is used in fire fighting applications. Mechanical transmission unit comprises of two identical rollers. These components are mounted on a suitably designed moving trailer. This typical trailer can also be mounted on fire tender and driven by the hydraulic energy available through the high pressure and high discharge pumps.

HDWMT is fabricated so as to obtain motion in the direction of fluid flow inside the hose. Hydraulic power is sufficiently available and can be easily converted into work done. It is evaluated by using experimentation and a mathematical model is formulated to calculate tractive force and velocity of trailer. This model has been developed using dimensional analysis approach based on the Buckingham π theorem for a HDWMT. Mathematical model is formed for Hydraulically driven water monitor trailer (HDWMT) to calculate the tractive force and velocity (Umbarkar, Kadu 2016). To reduce fire extinguishing time and loss of property mathematical model will prepare.

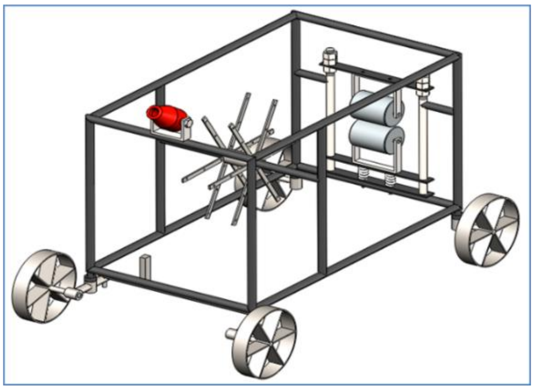

Fig. 1. a Actual working model of HDWMT Fig 1.b Prototype model of HDWMT

2. Design of HDWMT for fire fighting

HDWMT is a remote-controlled system and consists of a mobile and a rigid chassis. Its nozzle is designed in such a that, it can be operated at different heights and angles in order to control fire. The unique feature of this design is it will minimize the risks faced by fire fighters during their fire fighting. HDWMT is a ground trailer of compact size that can move fast, light weight, able to steer, equipped with long-range control ability for fire fighting and rescue purpose. The HDWMT is capable of fire fighting and rescue purpose in a small and hazardous environment. In addition to this, the HDWMT uses green energy, which is hydraulic, to power the system.

3. Development of π model

The mathematical model can be formed to investigate the relation between inputs and outputs variables. The interactive influence of HDWMT parameters such as Pressure, Density, Discharge, Diameter of hose, Gap between roller, Acceleration due to gravity, Weight of Trailer, Diameter of the wheel, Tractive force and Velocity. Tractive force and velocity are the dependent parameters and other inputs are independent parameters. (Scheck, 1961) The Independent and dependent variables mentioned above are listed below in Table No. 1. (Kadu, Awari, Sakhle & Modak, 2014).

Sl. No.	Parameter	Abbreviation Used/ Symbol	Unit	Dimensions MLT form	D / I Variable
1	Pressure	P	N/m^2	$[M^1L^{-1}T^{-2}]$	I
2	Density	ρ	Kg/m^3	$[M^1L^{-3}]$	I
3	Discharge	Q	m^3/s	$[L^3T^{-1}]$	I
4	Diameter of hose	d	m	$[L^1]$	I
5	Gap between roller	G_r	m	$[L^1]$	I
6	Acceleration	g	m/s^2	$[L^1T^{-2}]$	I

	due to gravity				
7	Weight of Trailer	W_T	N	$[M^1L^1T^{-2}]$	I
8	Diameter of wheel	D_w	m	$[L^1]$	I
9	Tractive force	F	N	$[M^1L^1T^{-2}]$	D
10	Velocity	V	m/s	$[L^1T^{-1}]$	D

Table 1. Dependent (D) and Independent (I) variables

4. π Terms Equation Formation

Independent variables of HDWMT are reduced to set of seven π terms. Equation of π terms is shown in Table 2.

Sr. No.	Particulars	Remark
1.	F =	$f(P, d, g, Q, G_r, D_W, W_T, \rho, V)$
2.	$f_1(F, P, d, g, Q, G_r, D_W, W_T, \rho, V)$ = constant	
3.	π_1	$P^{a1}d^{b1}g^{C1}Q$
4.	π_2	$P^{a2}d^{b2}g^{C2}G_r$
5.	π_3	$P^{a3}d^{b3}g^{C3}D_W$
6.	π_4	$P^{a4}d^{b4}g^{C4}W_T$
7.	π_5	$P^{a5}d^{b5}g^{C5}\rho$

Table 2. Equation of π Terms.

4.1. Calculations for indices of π-terms:

With respect to theory of Buckingham π theorem, the determination of pi terms is discussed below:

i.e., $\pi_1 = P^{a1}d^{b1}g^{C1}Q$

$$[M^0L^0T^0] = [ML^{-1}T^{-2}]^{a1}[L]^{b1}[LT^{-2}]^{c1}L^3T^{-1}$$

$\therefore 0 = a_1$

$0 = -a_1 + b_1 + c_1 + 3$

$$b_1 + c_1 = -3$$

$-2a_1 - 2c_1 - 1 = 0$

$$-2c_1 = 1$$

$$\therefore \ c_1 = \frac{-1}{2}$$

$$b_1 = -3 + \frac{1}{2}$$

$$\therefore\ b_1 = \frac{-5}{2}$$

$$\therefore\ \pi_1 = P^0 d^{\frac{-5}{2}} g^{\frac{-1}{2}} Q$$

$$\pi_1 = \frac{Q}{d^{5/2}\sqrt{g}}$$

Similarly, the values of π_2 to π_7 are calculated. The reduction of independent variables into π terms are shown in Table 3.

Sl. No.	Dimensionless ratio of π terms	Physical quantities
1	$\pi_1 = \frac{Q}{d^{\frac{5}{2}}\sqrt{g}}$	Discharge of water form pump
2	$\pi_2 = \frac{G_r}{d}$	Geometric parameter
3	$\pi_3 = \frac{D_W}{d}$	Geometric parameter
4	$\pi_4 = \frac{W_T}{Pd^{\frac{3}{2}}g^{\frac{1}{2}}}$	Weight of trailer
5	$\pi_5 = \frac{\rho d^2}{Pg}$	Density of water
6	$\pi_6 = \frac{F}{pd^2}$	Tractive force
7	$\pi_7 = \frac{V}{\sqrt{gd}}$	Velocity of trailer

Table 3. Reduction of Independent variable into π terms

In the present work it is intended to establish the exact empirical form of equations based on experimental data is formed.

$$\pi_{D1} = K_1\ \pi^{a1}\ \pi^{b1}\ \pi^{c1}\ \pi^{d1}\ \pi^{e1} \quad (1)$$

$$\pi_{D2} = K_2\ \pi^{a2}\ \pi^{b2}\ \pi^{c2}\ \pi^{d2}\ \pi^{e2} \quad (2)$$

The above prediction equation is formed by allowing one π term to change at a time while keeping the other π terms constant. The resulting changes in the Tractive Force and velocity of Trailer are observed. An approximate generalized empirical prediction model of the Force and velocity has been established. There are two dependent variable, i.e. Tractive Force (π_{D1}), Velocity (π_{D2}) were developed. (Belkhode, 2017)

4.1.1 Model for Tractive force and Velocity of Trailer

$$\pi_{D1} = f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5) \quad (3)$$

$$\pi_{D1} = K_1(\pi_1)^{a1} (\pi_2)^{b1} (\pi_3)^{c1} (\pi_4)^{d1} (\pi_5)^{e1} \quad (4)$$

In equation (*4*) there were six unknown terms , i.e a_1 to e_1 and K_1, where K_1 is curve fitting constant and remaining parameters are indices. It is required minimum Five π terms values i.e. π_1 to π_5 to get the values of these unknown parameters. Total 160 sets of these values are available by the existing plan of experimentation. It may not result in one best unique solution representing a best-fit unique curve for the remaining sets of values, if randomly any five sets selected from 160 data sets and values of unknowns K_1 and indices are calculated. In this experimentation, solving ${}^{160}C_5$ sets for finding solutions would be a monotonous task. Hence, it was decided to use curve fitting technique to solve this problem. Equation No. (5), mentioned below is used to solve by this technique (Makade, Chakrabarti, Jamil and Sakhale, 2020)

$$Z = a + (b*x) + (c*y) + (d*z) \quad (5)$$

By putting log on both the side of equation 5 we can get

$$\text{Log } \pi_{D1} = \log K_1 + a1\log(\pi_1) + b1\log(\pi_2) + c1\log(\pi_3) + d1\log(\pi_4) + e1\log(\pi_5)$$

Let, Log (πD1) =Z1, log(K1)= k1, log(π1)=A, log(π2)= B, log(π3)=C, log(π4)=D,log (π5)= E

The equation (5) may be written in the below mentioned format

$$Z_1 = k_1 + (a1*A) + (b1*B) + (c1*C) + (d1*D) + (e1*E) \quad (6)$$

The regression equation (6) of Z_1 consists of A, B, C, D and E. This represents a regression hyper plane n a n-dimensional coordinate system. The values of a1 to e1 are calculated to determine the regression hyper-plane. Multiplying equation (6) by A, B, C, D and E one at a time. MATLAB software is used to solve this equation by matrix method.

Z = k1+a*A+ b*B+ c*C+ d*D+ e*E

AZ=Ak1+aA2+bAB+cAC+dAD+eAE

BZ=Bk1+aAB+bB2+cBC+dBD+eBE

CZ1=Ck1+aCA+bBC+cC2+dDC+eEC

DZ1=Dk1+aAD+bDB+cDC+dD2+eDE

EZ1=Ek1+aEA+bEB+cEC+dED+eE2

We get Matrix of Z 6x6 multipliers of a1 to e1 and k1 on R.H.S

Y= 6x1 matrix of the terms

X= 6x1 matrix values of k1, a1 to e1.

$Z=X\times Y$

$Y=X^{-1}Z$

Therefore, a probable empirical form for Tractive force; π_{D1}

$$\pi_{D1}=115419.71 X\pi_1^{0.12648}\ X\pi_2^{0.113586}\ X\pi_3^{0.400984}\ X\pi_4^{0.07187}\ X\pi_5^{-0.010289} \quad (7)$$

and the probable empirical form for Velocity of trailer; π_{D2}

$$\pi_{D2}= 4883.83X\ \pi 1^{0.125429} X\pi 2^{-0.053}\ X\pi 3^{0.827847}\ X\pi 4^{-0.8411}\ X\pi 5^{-0.0619525} \quad (8)$$

5. Quantitative analysis of the data

An attempt has been made here using experimental data based modelling, to obtain the results interaction of π (independent) terms and to quantify or evaluate the behaviour of the real phenomenon. We have adopted quantitative analysis model of Tractive Force and Velocity of Trailer.

5.1 Data Analysis in view of Model indices

Interaction of various independent π terms in the models are indicated by indices. The influence of indices of the various independent π terms for the experimental investigation of formulated models. The influence of indices is studied for the data of each dependent π terms (computed from the models) for model of Tractive force and velocity of trailer is given below. (Belkhode, 2019)

The analysis of model for dependent π term $\pi_{D1}$for tractive effort:

The model for tractive effort is given below,

$$\pi_{D1} = \frac{F}{pd^2}$$

The derived empirical equation for tractive effort is given by,

$$\pi_{D1}= 115419.71\ \pi_1^{0.12648}\ X\pi_2^{0.113586}\ X\pi_3^{0.400984}\ X\pi_4^{0.07187}\ X\pi_5^{-0.010289}$$

It is found that, the effect of indices influence of independent π terms on the responses are as follows

a. The index π_3 (diameter of wheel) is 0.400984 and it is highest among all the other indices in the above equation. The positive value of this index indicates, diameter of wheel is directly proportional to tractive force.

b. Index of π_5 (Density of water) is -0.010289 and it is lowest among all the other indices. The negative value of this index indicates, Density of water is inversely proportional to tractive force.

c. The other π terms that are a direct impact on π_{D1} as per their indexes,

π_1, π_2 and π_4 having their values 0.12648, 0.113586 and 0.07187.

Those having positive indices direct relationship whereas negative indices show the inverse relationship with π_{D1}.

Analysis of velocity of trailer model:

The model for π_{D2} is given below.

$$\pi_{D2} = \frac{V}{\sqrt{gd}}$$

The empirical equation for this π term is given by,

$$\pi_{D2} = 4883.83 X\ \pi_1^{0.125429} X\pi_2^{-0.053}\ X\pi_3^{0.827847}\ X\pi_4^{-0.8411}\ X\pi_5^{-0.0619525}$$

a. The index of π_3 (diameter of wheel) is 0.827847 it is highest among all the other indices in the above equation. The positive value of this index indicates, diameter of wheel is directly proportional to velocity of Trailer.

b. The absolute index of π_4 (Weight of Trailer) is -0.8411 and it is lowest among all other indices. The negative value of this index indicates that Weight of Trailer is inversely proportional to velocity of Trailer

c. The remaining direct influencing π terms of this model are π_1, π_2, π_5.and their index values are respectively 0.125429, -0.053 , -0.0619525 The π terms with a positive index means any increment in these π terms the π_{D2} will be increases or otherwise. Those have a negative index indicates that in any increment the π_{D2} decreases.

6. Optimization

"Optimisation is the process of obtaining best result under given circumstances" In this research paper, we have calculated the optimised value of Tractive force and velocity of Trailer by using MS-Solver. (Rao, 1994).

6.1 Optimization of model for Tractive Force

The derived empirical equation for tractive force is given by,

$$\boldsymbol{\pi_{D1} = 115419.71\ \pi_1^{0.12648}\ X\pi_2^{0.113586}\ X\pi_3^{0.400984}\ X\pi_4^{0.07187}\ X\pi_5^{-0.010289}} \quad (9)$$

π_{D1} = k1 * (π1) a1 * (π2) b1 * (π3) c1 * (π4) d1 * (π5) e1

Substitute log on both the sides

Log [π_{D1}] = Log [k1 x (π1) a1 * (π2) b1 * (π3) c1 * (π4) d1 * (π5)e1]

$Z = K`_1 + (a1\ x\ X_1) + (b1\ x\ X_2) + (c1\ x\ X_3) + (d1\ x\ X_4) + (e1\ x\ X_5)$

$Z = \log(115419.71) + 0.12648\log(\pi_1) + 0.113586\log(\pi_2) + 0.400984\log(\pi_3) + 0.07187\log(\pi_4) - 0.010289\ \log(\pi_5)$

$Z = 5.06 + 0.12648X_1 + 0.113586X_2 + 0.400984X_3 + 0.07187\ X_4 - 0.010289\ X_5$

Subject to fallowing constraints

$(1 * X_1) + (0 * X_2) + (0 * X_3) + (0 * X_4) + (0 * X_5) \leq 1.13388$

$(1 * X_1) + (0 * X_2) + (0 * X_3) + (0 * X_4) + (0 * X_5) \geq -0.4587$

$(0 * X_1) + (1 * X_2) + (0 * X_3) + (0 * X_4) + (0 * X_5) \leq 0.2263$

$(0 * X_1) + (1 * X_2) + (0 * X_3) + (0 * X_4) + (0 * X_5) \geq -0.49831$

$(0 * X_1) + (0 * X_2) + (1 * X_3) + (0 * X_4) + (0 * X_5) \leq 0.897338$

$(0 * X_1) + (0 * X_2) + (1 * X_3) + (0 * X_4) + (0 * X_5) \geq 0.6320$

$(0 * X_1) + (0 * X_2) + (0 * X_3) + (1 * X_4) + (0 * X_5) \leq 5.5380$

$(0 * X_1) + (0 * X_2) + (0 * X_3) + (1 * X_4) + (0 * X_5) \geq 4.1397$

$(0 * X_1) + (0 * X_2) + (0 * X_3) + (0 * X_4) + (1 * X_5) \leq 5.5380$

$(0 * X_1) + (0 * X_2) + (0 * X_3) + (0 * X_4) + (1 * X_5) \geq 1.6074$

Apply MS Solver to solve the above problem,

$X_1=-0.45876$, $X_2=-0.226396$, $X_3= 0.632023$, $X_4=5.538023$, $X_5=5.5380$

$Z=5.570728$

6.2 Optimization of model for Velocity of trailer

$$\pi_{D2}= 4883.83X\ \pi_1^{0.125429} X\pi_2^{-0.053}\ X\pi_3^{0.827847}\ X\pi_4^{-0.8411}\ X\pi_5^{-0.0619525} \qquad (10)$$

Substitute log on both the sides in equation (10) and solving it further,

$Z= \log (4883.83) +0.1254290 \log (\pi_1) - 0.053 \log (\pi_2) +0.827847 \log (\pi_3) - 0.8411\log (\pi_4) - 0.0619525 \log (\pi_5)$

$Z = K`_2 + (a2 * X_1) + (b2 * X_2) + (c2 * X_3) + (d2 * X_4) + (e2 * X_5)$

$Z= 3.6887+0.1254290\ X_1 - 0.053\ X_2+ 0.827847\ X_3 - 0.8411\ X_4 + 0.0619525\ X_5$

Similarly, subjected to constrain by applying MS Solver to solve the above problem,

We get,

$X_1= (- 0.45876)$, $X_2= (- 0.226396)$, $X_3= 0.632023$, $X_4=5.538023$, $X_5=5.5380$

$Z= (- 0.172573)$

By using MS solver, the values of X_1 to X_4 and Z are calculated.

π_{1min} = Antilog of Z

By taking the antilog of X_1 to X_4 and Z the values of the independent π terms are obtained A similar procedure is adopted to optimize the models for π_{D1} and π_{D2}. [8]

Terms	**Tractive force : π_{D1} max**		**Velocity of Trailer: π_{D2} max**	
	π terms log values	π terms antilog	π terms log values	π terms antilog

		values		values
Z	5.570728	372158.54	-0.172573	0.67208
X_1	-0.45879	13.6106	-0.45879	13.6106
X_2	0.226396	0.3174	0.226396	0.3174
X_3	0.632023	7.8947	0.632023	7.8947
X_4	5.5380	345143.739	5.5380	345143.739
X_5	5.5380	345143.739	5.5380	345143.739

Table 4. Optimized value of Tractive force and Velocity of Trailer.

7. Neural analysis

The complex relationships between input and output data are solved by the powerful tool artificial neural network. The expert system ANN is efficient in simulating the complicated phenomena due to its non-linear structures (kadi, 2006)

Fig. 2 Algorithm steps for ANN

7.1 Neural analysis of Tractive Force

The feed forward neural network approach is used for approximation of the nonlinear functions. ANN is carried for tractive effort and velocity of trailer in reference all π terms. ANN simulation is plotted and shown in Fig 3.

The blue lines represented actual readings and the values generated by mathematical model are shown in red lines. The mathematical model of $\pi D1$ is plotted after talking its logarithm.

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It is observed that π6 varies directly with respect to hydraulic force ad its values are more sensitive for observation number 30 -70.

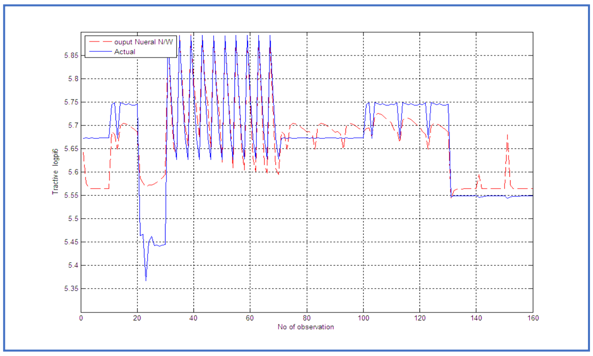
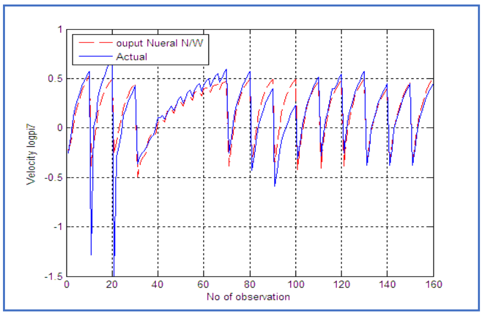


Fig. 3 |Neural Analysis of Tractive Force

7.2 Neural Analysis for Velocity of Trailer

The simulated values of velocity of trailer are represented in Fig 4. The blue lines represented actual readings and the values generated by mathematical model are shown in red



lines. The mathematical model of π_{D2} is plotted after talking its logarithm. It is oberved that π_7 varies directly with respect to velocity and its values are more sensitive for obesrvation number 30 -70.

Fig. 4 |Neural Analysis of *Velocity of Trailer*

8. Conclusions

Mathematical model is developed for Hydraulically driven water Monitor trailer for fire fighting. The value of curve fitting constant for Tractive force and velocity of trailer is calculated i.e., 115419.17 and 4883.83 respectively. The mathematical model established during this research is feasible and validated using different optimization tools. Therefore, this model can be used for the development of such trailers for different applications.

Mathematical models showed, Diameter of wheel is most significant value indicates it is in direct relation with tractive force. Density of water is least significant value among all the other variables. Diameter of wheel is most significant value indicates velocity of trailer and it is also in direct relation with velocity of trailer. Weight of Trailer is least significant value among all the other variables.

Experimental values are collected by performing the operations with HDWMT model developed. The experimental values are compared with mathematical model using ANN. It is observed that very positive correlation between experimental and mathematical model and complementary to each other.

Data Availability Statement

The authors declare that the primary data supporting the findings of this study are available within the paper. Secondary datasets generated during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest None

References

1. Vladimirs. Nikitin , Sergey A. Golubin , Roman B. Belov & Nikitav. Andrianov, 2019 , Multi-Agent Remote Control System For Extinguishing Forest Fires With Heterogeneous Elements Of A Robotic Complex, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2250–2378; ISSN (E): 2319–4510 Vol. 9, Issue 6, Dec 2019, 25–32
2. Lu Li , Aduwati Sali , Nor Kamariah Noordin , Alyani Ismail , Fazirulhisyam Hashim , Mohd Fadlee A. Rasid , Marsyita Hanafi , Sheriza Mohd Razali , Nurizana Amir Aziz , Imas Sukaesih Sitanggang , Lailan Syaufina and Ati Dwi Nurhayati, 2023, Modeling of Evaporation Rate for Peatland Fire Prevention Using Internet of Things (IoT) System, MDPI,Fire 2023, 6, 272. https://doi.org/10.3390/fire6070272,
3. Manual of fire fighting, Book 7, 1987 , issued under the authority of home office (fire department), London (U.K.),Hydraulics, pumps, and pump operation.
4. Larin, O.; Morozov, O.; Nazarenko, S.; Chernobay, G.; Kalynovskyi, A.; Kovalenko, R.; Fedulova, S.; Pustovoitov, P., 2019, Determining Mechanical Properties Of A Pressure Fire Hose, Eastern-European Journal of Enterprise Technologies, 2019, Vol 102, Issue 7, p-63
5. Prashant S. Kadu and Amit R Bhende, 2010, Behavioral Analysis of Hydraulically Driven Fire Fighting Water Monitor Trailer, Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management Dhaka, Bangladesh, January 9 – 10, 2010
6. H. Schenck Jr. 1961, Theory of Engineering Experimentation, New York. McGraw Hill;
7. Prashant Umbarkar and Prashant S. Kadu, 2016, Design and development of steering mechanism for hydraulically driven fire fighting trailer, Advances in Applied Science Research, 2016, 7(1):171-183.
8. [8] R.S. Kadu, G.K.Awari, C.N.Sakhle, J.P.Modak, 2014,Formulation of Mathematical Model for the Investigation Tool Wears in Boring Machining Operation on Cast Iron Using Carbide and CBN Tools, Procedia Materials Science, Vol 6, 1710-1724
9. Belkhode PN. 2017, Mathematical modelling of liner piston maintenance activity using field data to minimize overhauling time and human energy consumption. J Inst Eng (India): Series C Springer Publication 2017.
10. Rahul G. Makade , Siddharth Chakrabarti , Basharat Jamil , C.N. Sakhale, 2020, Estimation of global solar radiation for the tropical wet climatic region of India: A theory of experimentation approach, Renewable Energy, Volume 146, February 2020, Pages

2044-2059
11. Pramod N. Belkhode, 2019, Development of mathematical model and artificial neural network simulation to predict the performance of manual loading operation of underground mines, Journal of material research and Technology, 2309-2315.
12. Rao SS, 1994, Optimization theory & applications. Wiley Eastern Limited.
13. Hany El Kadi,2006, Modeling the mechanical behavior of fiber-reinforced polymeric composite materials using artificial neural networks—A review, Composite Structures Volume 73, Issue 1, May 2006, Pages 1-23