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Research Article

Prediction the Performance Rate of Chain Type Trenching Machine

Mohamed Ibrahim GHONIMY[ID][a,b*]

[a]*Department of Plant Production and Protection, College of Agriculture and Veterinary Medicine, Qassim University, Buraydah, SAUDI ARABIA*

[b] *Department of Agricultural Engineering, Faculty of Agriculture, Cairo University, Giza, EGYPT*

(*): Corresponding author; mohamed.ghonimy@agr.cu.edu.eg

ABSTRACT

The mathematical analysis for estimating the performance rate "*RP*" of chain-type trenching machine was studied. The mathematical analysis ended with an equation for this type. This mathematical equation was checked under different operating conditions. The practical study of the performance rate showed that the deviation of the theoretical performance rate from the actual performance rate ranged from -3.4 to +2% only for the 150.7 cm and 120.7 cm trench depth respectively. The machine field efficiency ranged from 46.7 to 57% for the 150.7 cm and 120.7 cm depth respectively. It also showed an increase in machine field efficiency by decreasing the trench depth.

RESEARCH ARTICLE

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INTRODUCTION

The drainage of agricultural land is one of the main operations which affecting the production of agricultural crops (Vlotman *et al*., 2020). The productivity of the agricultural crops increased by 22-35% when implementing agricultural drainage projects (Kovalenko *et al*., 2020). Several trenching machines excavate the tile drainage trenches. There are mainly three types of trenching machines different in their construction and way of performance. These three types are chain-type trenching machines, wheel type trenching machine and plow type trenching machines.

Day (1973) defined the productivity of trenching machines as the rate the excavator can move along the trench line. The rate of excavation for a continuous trenching machine is its controlled productivity. It will vary with the width and depth of trench, the toughness of the material to be excavated and the power available or selected by the operator. Peurifoy (1970) studied the productivity in trenching operations. He found many factors affecting the production rate of trenching machine. These include the class of soil, depth and width of trench, extent of shoring required, topography, climatic condition, extent of vegetation such a trees, stumps and roots, and physical obstruction, such as buried pipes, sidewalks, paved streets, building etc.

In case of laying a pipeline, the speed with which the pipe can be placed in the trench, also affect the production rate of the machine. Sitorus *et al.* (2016) reported that the digging machine forward speed, cutting depth, uniaxial compressive strength, and trench width are the most sensitive parameters affecting the power and angular speed. Design optimization using the information drawn from this parameter study can be preceded by focusing on the selection of traverse speed, uniaxial compressive strength, trench width, carrier weight, nose radius, bar length, and pivot point location. Spencer *et al.* (2007) described the principal features of the upgraded trenching and methods of calculating predicted trenching performance and they found that the target performance rate for wheel type trenching machine ranged from 80 to 400 m h^{-1} according to soil type. Schwab *et al.* (1982) studied the productivity in trenching operations. They found many factors affecting it such as; soil moisture, soil characteristics as hardness and stickiness, stones, and submerged stumps, depth of trench, conditions of the trenching machine, the ski1l of the operator, and the delays due to interruptions during operation. They found that an extremely wet soil may stop machine operation. Soil with a low moisture content may not affect the digging rate to any extent, but soil that stick to the buckets of the machine, sandy soils that fall apart easily, and deep cuts reduce digging speed. They also found that increasing the depth from 90 to 150 cm decreased the digging speed by 56% under Iowa and Minnesota conditions. Donahue *et al.* (1985) mentioned that the soil moisture, soil characteristics, skill of operator, width of the trench, and depth of the trench influence the factors affecting the capacity of the trenching machines.

There is a several research concerned with the use of mathematical models for trenching machines. Diep (2017) found that the chipping depth of a chain trenching machine is related to the tangential tooth speed *(ut)*, the traverse speed *(U)*, the spacing between teeth *(S)* and the angle of the cutting assembly *(Φ)*. If working length of the tooth is known, the maximum of traverse speed U can be determined by the following formula h_{max}=U/ut.S , where h_{max} is the theoretical maximum cutting depth occurs with cutting angle Φ = 90°. Du *et al.* (2016) found that the operator control inputs to execute a work cycle of an excavator trenching operation. The simulation results in a work cycle that is generated by executing a series of tasks in the way a human operator would perceiving the state of the machine, deciding when to transition from one task to the next, and controlling the machine to move the bucket through the tasks. The virtual operator model appropriately adapted to different operator control strategies, machine parameters changes (i.e. pump speed) and a change in work site goals (trench depth, pile location). The model-generated outputs based on human-like perception, decision-making, and action selection. Reddy and Shailesh (2018) mentioned that, in order to increase the life of backhoe excavator bucket tooth other two materials i.e.

HSS and HCHCr has been analyzed for the similar force and boundary conditions. 3D model was prepared in solid works and software in finite element method (FEM) domain was utilized for analyzing the model or excavator bucket tooth behavior. Computational approach will give the closer results to practical values through simulation. Computer Aided Engineering (CAE) can drastically reduce the costs associated with the product lifecycle.

Whatever the type of the trenching machine is, it has the advantage of quite high rate of performance, since it simultaneously digs the trench, lays down the tiles or the pipes and, in some types, it also refills the ditches with the soil. This means fulfilling its did define this complete function in a short period within the same day. It is characterized with the high accuracy in laying the pipes or the tiles at the required depth and slope. Besides, these types of trenching machines suppress the manual way of digging and laying drainage pipes by its lower costs of operation (Schaufelberger and Migliaccio, 2019).

The aim of this work was to find out the main factors affecting chain-type trenching machine performance rate, relate these affecting factors in mathematical relationship, and validate the mathematical relationship to predict the performance rate of chain-type trenching machine.

MATERIALS AND METHODS

Mathematical analysis approach

The mathematical analysis had to be preceded with the two main steps which were to state the theory, the construction the specifications and the dimensions of the applied mechanism for chain-type trenching machine, Figure 1, and to state the expected affecting factors on the performance of the applied mechanism, the nature and the magnitude of their effects. The performance rate of the trenching machine depends, to a great extent, on the forward speed of the machine. This forward speed in return, is related to both the size of the power source of the trenching machine and the magnitude of the consumed power during the performance of the machine. Therefore, the mathematical analysis depended on expressing the magnitude of any required power of the trenching machine as a function of machine forward speed. By equating the size of the power source with the summation of the required powers during machine performance (equation 1), the magnetite of the maximum machine forward speed can be estimated, and hence, the rate of performance of the machine can be determined.

$$P_b = P_c + P_r + P_i + P_s + P_t + P_e \pm P_a + P_n \quad (1)$$

Where:

P_b = brake power of the engine of the machine, kW;

P_c = pulling power needed for cutting, kW;

P_r = pulling power to overcome rolling resistance, kW;

P_i = pulling power to overcome slope resistance, kW;

P_s = power lost in slop resistance, kW;

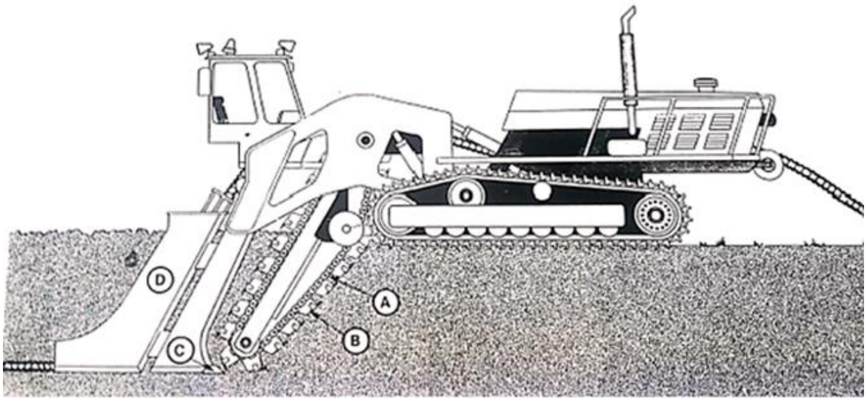
P_t = power 1ost in transmission systems, kW;

P_e = power required to lift the cut soil, kW;

P_a = power required to overcome air resistance, kW;
P_n = power required to accelerate the machine to the operating speed due to its inertia, kW.

Both P_a and P_n could be neglected since the operating forward speeds of the trenching machine are very limited compared with any other moving truck. Therefore, equation (1) can be simplified as shown in the following equation (2).

$$P_b = P_c + P_r + P_i + P_s + P_t + P_e \quad (2)$$



A) Endless rotating chain B) Cutters attached to chain
C) Shoe to smooth trench bottom D) Tubing (or tile) shute

Figure 1. Chain-type trenching machine. "After Shady 1989"

The theory, construction, and specifications of the mechanisms of chain-type trenching machine:

The excavating unit of the chain-type trenching machine, Figure 2, mainly consists of an endless chain, which moves along a boom at a speed *(V_c)*. The angle of the chain with the vertical direction is *(θ)*. On the chain, there are attached cutter buckets equipped with teeth. The inclined distance between the cutting edges of any two consecutive buckets is *(S_b)*. The depth of the digged trench is *(d)*. The performance theory of chain-type trenching machine is that the machine moves horizontally at a veracity *(V_m)*, the chain moves in an inclined direction with an angle equals (θ) at a speed *(V_c)*. The absolute speed of the cutting edge of the bucket *(V_b)* can be considered as the summation of the vectors of *(V_m)* and *(V_c)* as shown in Figure 3. The cutting edges of the consecutive buckets cut the soil in thin inclined layers. The buckets elevate the cut soil and throw it outside the digged trench.

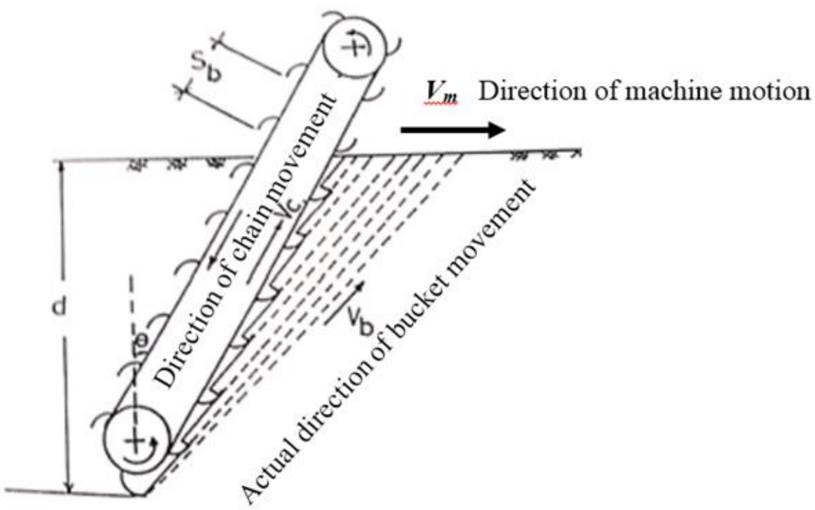


Figure 2. The mechanism of chain-type trenching machine.

Factors affecting the performance of the trenching machines

There are many factors affecting the performance rate of the trenching machines. These factors can be classified into two groups; **soil factors** which include soil specific weight *(ω)*, N cm^{-3}, soil unit draft *(U)*, N cm^{-2}, traction coefficient, rolling resistance coefficient *(RR)*, angle between inclined soil surface and the horizontal direction *(ψ)*, and friction coefficients between soil and soil and between soil and metal *(F_{ms})*.

Machine factors, which include machine weight *(W_m)*, N, machine brake power *(P_b)*, kW, machine forward speed (V_m), m s^{-1}, trench cutting width *(W_t)*, cm, vertical depth of the cut trench *(d)*, cm, slip percentage of the tractor device of the machine *(S)*, machine transmission efficiency (η_t), and machine field efficiency (η_f), chain speed *(V_c)*, m s^{-1}, and angle of chain with vertical direction *(θ)*.

Some assumptions and simplifications were done in order to facilitate mathematical manipulation. These include Homogeneous and isotropic soil, with a constant unit draft. Constant velocities for any moving element, i.e., constant forward machine speed, and constant chain speed were assumed. The paths of the cutting edge for the chain-type trenching machines were considered as straight lines.

Mathematical analysis for estimating the performance rate

The mathematical analysis for estimating the performance rate *(RP)* of the chain-type-trenching machine is expected to be in the form of the equation (2):

$$RP = 60 \times V_m \times \eta_f \qquad (3)$$

Where:
RP = the actual performance rate of the machine, m min^{-1};
V_m = the machine forward speed, m s^{-1};
η_f = the field efficiency, decimal.
To find out the value of V_m, the components of equation (2) were obtained as the following:

a) Determination of P_c

Referring to Figure 4:

$$P_c = 0.001\left(F_c + F_f\right) \times V_b = 0.001(U.W_t.\delta.N + F_{ms}(1000\,P_b.\eta_t/V_m)cos\phi) \times V_b \quad (4)$$

$$P_c = 0.001 \times U^* \times W_t \times \delta \times N \times V_b \quad (5)$$

Where:

$U^* = K^*.\ U$

$$K^* = \frac{U^*}{U} = \frac{[U.W_t.\delta.N(1000.F_{ms}.P_b.\eta_t/V_m)cos\phi].V_b}{U.W_t.\delta.N.V_b}$$

$$K^* = 1 + \frac{(1000.F_{ms}.P_b.\eta_t/V_m).cos\phi}{U.W_t.\delta.N.V_b} \cong from\ 5\ to\ 15$$

Using reasonable values for chain-type trenching machines, means that utilizing unit draft (U^*) including friction can be as much as about twelve times the unit draft *(U)* used in soil ploughing.

Referring to Figures 2 and 3;

$$N = \frac{d}{cos\theta.S_b}\ and\ \delta = \frac{V_m}{V_b}.cos\theta.S_b$$

$$\therefore P_c = 0.001\,K^*.U.W_t.d.V_m \therefore P_c = 0.001\,K^*.U.W_t.d.V_m \quad (6)$$

b) Determination of P_r

$$P_r = 0.001\,F_r.V_m \quad (7)$$

The resistance force (F_r) due to rolling resistance depends on machine weight *(W_m)*, the weight of cut soil *(W_s)*, the rolling resistance coefficient (*RR*), the vertical component of the cutting force *(F_{cv})*, and the angle ψ between inclined soil surface and the horizontal direction.

$$F_r = RR.cos\psi.(W_m + W_s + F_{cv})F_r = RR.cos\psi.(W_m + W_s + F_{cv}) \quad (8)$$

$$W_s = \frac{1}{2}W_t.\delta.N.l.\omega \qquad but \quad V_b.t = l$$

$$V_c.t = S_b.N = \frac{d}{\cos\theta}$$

$$W_s = \frac{\omega.W_t.d^2.V_m}{2\,cos\theta\,.V_c}$$

$$F_{cv} = \left(\frac{K^*.U.W_t.d.V_m}{V_b}\right).cos\phi$$

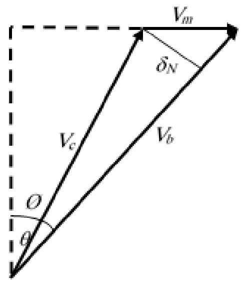
$$but \quad cos\phi = \frac{V_c.cos\theta}{V_b} \qquad and \qquad v_b = [(V_m)^2 + 2V_c.V_m.cos\theta + (V_c)^2]^{1/2}$$

$$F_{cv} = \frac{K^*.U.W_t.d.(V_c/V_m)\,.cos\theta}{1 + 2(V_c/V_m)\,.cos\theta + \,(V_c/V_m)^2}$$

Substituting into equations (8) and (7) gives

$$P_r = 0.001\,V_m.RR.cos\psi.\left[W_m + \frac{\omega.W_t.d^2}{2\,cos\theta.(V_c/V_m)} + \frac{K^*.U.W_t.d.(V_c/V_m)\,.cos\theta}{1 + 2.(V_c/V_m).cos\theta + (V_c/V_m)^2}\right]$$

$$P_r = 0.001\, V_m . RR. cos\psi . \left[W_m + \frac{\omega . W_t . d^2}{2\, cos\theta . (V_c/V_m)} + \frac{K^* . U . W_t . d . (V_c/V_m) . cos\theta}{1+2.(V_c/V_m).cos\theta + (V_c/V_m)^2} \right] \quad (9)$$



V_m= machine speed.
V_c = chain speed
V_b = resultant speed of the bucket edge
N= number of bucket in the cutting action.
δ = thickness of cut for one bucket.

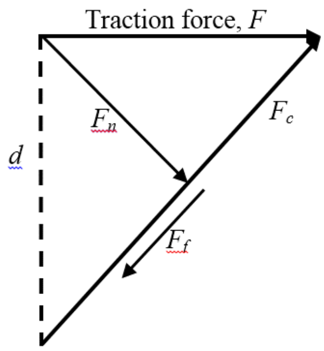


Figure 3. Bucket resultant speed.

Figure 4. Determination of the friction force F_f acting on bucket edge.

c) Determination of P_i

$$P_i = 0.001\, (W_m + W_S). sin\psi . V_m \quad (10)$$

$$P_i = 0.001\, V_m . sin\psi . \left[W_m + \frac{\omega . W_t . d^2}{2\, cos\theta . (V_c/V_m)} \right] \quad (11)$$

d) Determination of P_s

$$P_s = 0.001\, F_s . V_s = 0.001\, (F_c + F_r). V_s \quad (12)$$

Where;

P_s is the power lost in slip resistance.

F_c is the cutting force,

F_r is the resistance force due to rolling and

V_s is the loss in machine speed due slippage (S).

$$V_s = \left(\frac{S}{100-S} \right) . V_m \quad (13)$$

$$P_s = 0.001 \left[\left(\frac{S}{100-S} \right) . V_m \right] . \left[\frac{K^* . U . W_t . d}{\left[1+2.(V_c/V_m).cos\theta + (V_c/V_m)^2 \right]^{1/2}} + RR. cos\psi . \left(W_m + \frac{\omega . W_t . d^2}{2\, cos\theta . (V_c/V_m)} \right) + \frac{K^* . U . W_t . d . (V_c/V_m) . cos\theta}{1+2.(V_c/V_m).cos\theta + (V_c/V_m)^2} \right] \quad (14)$$

e) Determination of P_t

$$P_t = P_b . (1 - \eta_t) \quad (15)$$

f) Determination of P_e

$$P_e = 0.001\, W_S . V_c . cos\theta = 0.001 \times \frac{\omega . W_t . d^2 . V_m}{2} \quad (16)$$

From equations 2, 3, 9, 11, 14, 15 and 16

$$P_c + P_r + P_i + P_s + P_t + P_e - P_b = 0 \quad (17)$$

$$V^2{}_m\left[\left(\frac{\omega.W_t.d^2}{2cos\theta.V_c}\right).\left(RR.cos\psi+sin\psi+RR.cos\psi.\frac{S}{100-S}\right)\right]+V_m\left[K^*.U.w_t.d+RR.cos\psi.W_m+W_m.sin\psi+\frac{K^*.U.W_t.d.\left(\frac{S}{100-S}\right)}{\left[1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2\right]^{1/2}}+RR.cos\psi.W_m.\left(\frac{S}{100-S}\right)+\frac{\omega.W_t.d^2}{2}\right]+\left[\left(\frac{RR.cos\psi.K^*.U.W_t.d.cos\theta.V_c}{1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2}\right).\left(1+\frac{S}{100-S}\right)-1000P_b.\eta_t\right]=0$$

$$V^2{}_m+\frac{G}{Q}.V_m-\frac{J}{Q}=0 \qquad (18)$$

Where:

$$Q=\left(\frac{\omega.W_t.d^2}{2cos\theta.V_c}\right).\left(RR.cos\psi\left(\frac{100}{100-S}\right)+sin\psi\right) \qquad (19)$$

$$G=G_1+G_2+G_3 \qquad (20)$$

$$G_1=K^*.U.w_t.d.\left[1+\left(\frac{S}{100-S}\right).\left[1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2\right]^{-1/2}\right] \qquad (21)$$

$$G_2=RR.cos\psi.\left[V_m+W_m.\left(\frac{S}{100-S}\right)\right] \qquad (22)$$

$$G_3=W_m.sin\psi+\frac{\omega.W_t.d^2}{2}G_3=W_m.sin\psi+\frac{\omega.W_t.d^2}{2} \qquad (23)$$

$$J=\left(\frac{RR.cos\psi.K^*.U.W_t.d.cos\theta.V_c}{1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2}\right).\left(1+\frac{100}{100-S}\right)-1000P_b.\eta_t \qquad (24)$$

Applying the rule:

$$V_m=-\frac{b}{2}\pm\sqrt{\left(\frac{b}{2}\right)^2-\frac{C}{a}} \qquad (25)$$

$$\frac{b}{2}=\frac{G}{2Q} \qquad (26)$$

$$C=\frac{J}{Q} \qquad (27)$$

$$\frac{b}{2}=\left(\frac{cos\theta.V_c}{\omega.W_t.d^2.\left(RR.cos\psi\left(\frac{100}{100-S}\right)+sin\psi\right)}\right)\times\left\{K^*.U.w_t.d.\left(1+\left(\frac{S}{100-S}\right).\left[1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2\right]^{-1/2}\right)+RR.cos\psi.W_m.\left(1+\frac{S}{100-S}\right)+\left(W_m.sin\psi+\frac{\omega.W_t.d^2}{2}\right)\right\} \qquad (28)$$

$$C=\frac{2\ cos\theta.V_c}{\omega.W_t.d^2.\left(RR.cos\psi\left(\frac{100}{100-S}\right)+sin\psi\right)}\times\left[\left(\frac{RR.cos\psi.K^*.U.W_t.d.cos\theta.V_c}{1+2.(V_c/V_m).cos\theta+(V_c/V_m)^2}\right).\left(\frac{100}{100-S}\right)-1000P_b.\eta_t\right] \qquad (29)$$

Equation (25) could be solved by trial-and-error method using reasonable initial values of V_m in equations (28) and (29) and the value of $K^*\approx12$. When different values of K^* ranging from 1 to 15 were used, the estimated values of V_m ranged from 2.92 to o.26 m sec^{-1} respectively.

The actual performance rate *(RP)* could be obtained from equation (3) using field efficiency $\eta_f = \eta_s.\ \eta_w.\ \eta_{ti}$, where η_s is the efficiency of utilizing the geared speed, η_w is the efficiency of utilizing the proposed width of the machine, and η_{ti} is the efficiency of utilizing the time. However, due to the very low speed of the machine, both η_s and η_w could be considered equal to 1.0.

Field experimental work

The experimental work was carried out through a period of almost one year. It was conducted in Gharbia Governorate, in Sawahel El-Neel region, in which the chain-type trenching machine (Figure 5) was tested. The specification of the machine is shown in Table 1. Trench depths of 120 and 150 cm were tested.

Figure 5. The tested chain-type trenching machine. "i-bidder.com 2015"

Table 1. Technical specifications of the chain-type trenching machine.

Model	Barth Holland K171
Engine	Deutz diesel type
Power	149 kW (203 HP) - 2150 rpm
Tank capacity	Fuel 320 lit., Hydraulic oil 120 lit
Electricity	24 V.
Speed	variable (0 - 5000 m h^{-1})
Ground pressure	3 N cm^{-2}
Transmission efficiency	90%
Cutting system speed	1 gear: 1.04 m s^{-1} 2 gear: 2.15 m s^{-1} 3 gear: 3.26 m s^{-1} 4 gear: 4.35 m s^{-1} 5 gear: 5.75 m s^{-1} r. gear: 1.02 m s^{-1}
Max. trench depth	1750 mm
Trench width	230 or 280 mm
The angle of the chain with the vertical direction	30 degree
Chain pitch	100 mm
TRANSPORT DATA	
length	10905 mm
Width	2500 mm
Height	1000 mm
Weight	13 tons

RESULTS AND DISCUSSION

The average rolling resistance coefficient of the experimental field was taken as 4.0%, since it was found ranging between 3.0 and 5.0% (Jia *et al.*, 2018). The average specific weight of the soil *(ω)* was found to be 0.011 N cm^{-3} (Jia *et al.*, 2018). In addition, the average draft was taken as 10 N cm^{-2} (Jia *et al.*, 2018). The average values of field measurements were as shown in Table 2.

Table 2. Average values of field measurements for chain-type trenching machine.

Nominal trench depth, cm	120		150	
Field measurements	**Ave.**	**SD**	**Ave.**	**SD**
d, cm	120.70	2.37	150.7	2.15
W_t, cm	23.10	0.34	23.1	0.34
S, %	5.00	---	6.00	---
V_m, m s^{-1}	0.40	0.05	0.34	0.04
V_c, m s^{-1}	3.26	---	2.15	---
K^*	12.00	---	12.00	---
ψ, degree	0.00	---	0.00	---

d = Trench depth, W_t = Trench width, S = slip percentage, V_m = Machine forward speed, V_c = Chain forward speed, K^* = A dimensionless coefficient = (U^*/U), ψ = angle between inclined soil surface and the horizontal direction.

Actual performance rate *(RP)* and field efficiency *(η_f)*

The average values of breakdown items of the daily machine time, machine performance rate *(RP)*, field efficiency *(η_f)* as practically measured in the field are shown in Table 3. It is clear that the average values of *RP* were 13 and 9 m min^{-1} for 120 and 150 cm trench depth respectively while the η_f were 57 and 46.7% for 120 and 150 cm trench depth respectively.

Table 3. Breakdown items of the daily machine item for chain-type trenching machine and its average performance rate and field efficiency.

Activities	*Average spent time, min day^{-1} Trench depth, cm		SD, min day^{-1} Trench depth, cm	
	120	**150**	**120**	**150**
Net excavating and pipe laydown	229	215	7.26	5.81
Turning and travelling to start digging another trench	55	65	2.49	3.12
Setup time for reaching the depth	23	29	1.76	2.18
Rest periods	60	66	1.76	3.26
Field quick maintenances	30	30	2.17	1.73
Refill of water and oil tank	30	34	2.23	1.48
Other lost time	10	18	1.49	1.73
Average total time, min day^{-1}	485	455	8.15	7.21
**Total installed length, m day^{-1}	6305	4095	6.12	4.23
Actual performance rate, m min^{-1}	13.0	9.0	1.15	0.92
*** Field efficiency, %	57.0	46.7	0.89	0.81

* Average value of ten estimates, each for a different operating day.
**Average value (m/day) of the total excavated trench lengths within the ten days period.
***Average field efficiency within the ten days period.

Theoretical deterioration of the performance rate of the chain-type trenching machine

To theoretically predict the performance rate, equations (3), (25), (28), and (29) were applied. Using the above-mentioned data into equation (28) for the value of *b/2* and into equation (29) for the value of *C* gave the following equations:

For 120.7 cm depth

$$\frac{b}{2} = 6154.28 + \frac{316.97}{\sqrt{1 + \frac{5.65}{V_m} + \frac{10.63}{V^2{}_m}}}$$

$$C = \frac{1431.77}{1 + \frac{5.65}{V_m} + \frac{10.63}{V^2{}_m}} - 4827.6$$

For 150.7 cm depth

$$\frac{b}{2} = 3196.18 + \frac{199.98}{\sqrt{1 + \frac{3.72}{V_m} + \frac{4.62}{V^2{}_m}}}$$

$$C = \frac{4964.60}{1 + \frac{3.72}{V_m} + \frac{4.62}{V^2{}_m}} - 2011.5$$

Solving equation (18) by trial-and-error method, gave the computed values of the V_m, Table 4. Applying the computed values of the V_m into equation (3) gave the predicted value of the performance rate of the chain-type trenching machine:

RP (120.7 cm depth) = 60 x 0.388 x 0.57 = 13.26 m min^{-1}

This computed value was very close to the experimentally determined value of the performance rate for the 120.7 cm trench depth, which was found to be 13 m min^{-1}., Table 3 and Figure 6. The deviation of the theoretically computed value from the field determined value for the performance rate was only about + 2%.

RP (150.7 cm depth) = 60 x 0.31 x 0.467 = 8.69 m min^{-1}

This computed value was very close to the experimentally determined value of the performance rate for the 150.7 cm trench depth, which was found to be 9.00 m min^{-1}, Table 3 and Figure 6. The deviation of the theoretically computed value from the field determined value for the performance rate was only about - 3.4%.

Table 4. The initially proposed and the computed values in the interaction process for the determination of the forward speed of the chain-type trenching machine at different trench depths. (Using trial and error method).

Trench depth, cm	V_m, m s^{-1}	Trial 1	Trial 2	Trial 3	Trial 4
120.7	proposed value	3.000	1.000	0.400	0.388
	computed value	0.355	0.301	0.389	0.388
150.7	proposed value	3.000	1.000	0.400	0.310
	computed value	0.278	0.300	0.309	0.310

The findings of the used chain-type trenching machine show the degree of accuracy of the mathematically derived equations. This derived equation can be used with enough confidence to theoretically predict the performance rate of chain-type trenching machine depending on the prevailing operating conditions.

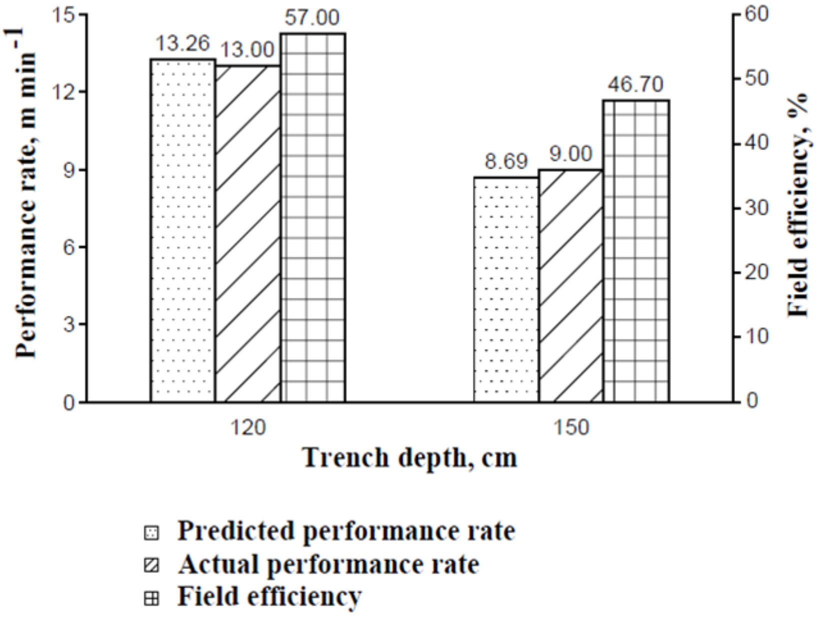


Figure 6. The actual & predicted performance rate and field efficiency of the chain-type trenching machine.

CONCLUSION

The digging of the trenches is an important process in order to implement the tail drainage projects. This research is concerned with studying the relationship that correlate the performance of the chain-type trenching machine with the factors affecting them, so that the rate of performance can be predicted or controlled through the factors affecting it. A mathematical analysis of chain-type trenching machine was performed. Also, a field operation study was conducted under actual operating conditions to test the validity of the derived mathematical equations.

The study showed the validity of the derived equations in predicting the performance rate of chain-type trenching machine. The percentage difference between the performance rate calculated from the equations and the actual field estimated performance rate were -3.4% and +2% at a trench depth of 150.7 and 120.7 cm respectively. The results of the field study also showed that the field efficiency was 46.7 and 57% for the chain-type trenching machine at a trench depth of 150.7 and 120.7 cm respectively. The finial equation of the mathematical model can be used to increase the performance rate of the chain-type trenching machine by maximizing all the factors in the numerator or by minimizing all the factors in the denominator.

Finally, the derived mathematical equation can be used with enough confidence to theoretically predict the performance rate of chain-type trenching machine depending on the prevailing operating conditions.

DECLARATION OF COMPETING INTEREST

The author declares that he has no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author, Mohamed Ghonimy, is responsible for the various parts of this paper.

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REFERENCES

Day DA (1973). Construction equipment guide. John Wiley and Sons.,Inc., N. Y., USA, 206-208.

Diep DD (2017). Analysis the Factors Affecting Conveyance Rate of Unbucket Chain Trenching Machine. *Agricultural, Forest and Transport Machinery and Technologies, 4(1): 38-44.*

Donahue RL, Miller RW and Shickluna GC (1985). Soil an introduction to soil and plant growth. 4th Ed. Prentice Hall, Inc., Englewood cliffs, *New Jersey*, USA. 98-106.

Du Y, Dorneich MC and Steward B (2016). Virtual operator modeling method for excavator trenching. *Automation in Construction, 70: 14-25.*

i-bidder.com 2015. Barth holland k171 trencher. [Online] Available from: https://www.i-bidder.com/en-gb/auction-catalogues/ml/catalogue-id-morris10019/lot-dd3f8267-bddc-47be-ab61-a50900a797df. (Accessed November 24, 2021).

Jia J, Jia and Schmidt (2018). Soil dynamics and foundation modeling. *Springer*, New York.

Kovalenko P, Rokochinskiy A, Mazhayskiy Y, Volk P, Volk L and Chernikova O (2020). Construction and agricultural drainage parameter optimization considering economic and environmental requirements. *Engineering for Rural Development*, *19: 1009-1017.*

Peurifoy RL (1970). Construction planning, equipment, and methods. 2nd ed. McGraw, Hill Kogakusha, Ltd., Tokyo, Japan, pp 695.

Reddy Y and Shailesh P (2018). Design and analysis of excavator bucket tooth. *International Journal of Modern Trends in Engineering and Research, 5(4): 79-86.*

Shady AM (1989). Irrigation drainage and flood control in Canada. Canadian international development agency, *Quebec*, Canada.

Schaufelberger JE and Migliaccio GC (2019). Construction equipment management. *Routledge*.

Schwab GO, Frevert RK, Edminster TW and Barnes KK (1982). Soil and water conservation engineering. *Soil Science, 134(2): 146.*

Sitorus PE, Ko JH and Kwon OS (2016). Parameter study of chain trenching machines of Underwater Construction Robots via analytical model. In OCEANS 2016 MTS/IEEE Monterey (pp. 1-6). IEEE.

Spencer A, Machin J and Jackson E (2007). Rock cutting With the T750 super trenching. Unmanned Intervention, *New Orleans*, LA, 30.

Vlotman WF, Smedema LK and Rycroft DW (2020). Modern land drainage: Planning, design and management of agricultural drainage systems. *CRC Press*.