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Minor Time Ratio in HDD Prereaming Time In Clayey Conditions – Case Study

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Abstract

Horizontal Directional Drilling (HDD) is defined as "A steerable system for the installation of pipes, conduits, and cables in a short, medium, and large drive length and in a shallow, medium, and deep arc using a surfaced launched drilling rig. Traditionally, HDD was launched and growth out from the oil and well drilling construction. HDD is applied to cross obstacles such as rivers, lakes, and valleys using a rotating bit or reamer with a fluid pumped to fill the pilot hole, that then will be enlarged by a larger reamer back and forth passes to the size required (125% to 150% of product pipe size or diameter). HDD after few years of application is acceptable as the very effective technique for the installation of pipelines and other utilities in sensitive and congested areas such as train tracks, railways and stations, and airports runways. This research focuses on the activities of HDD operation, including minor activities and major activities and the percentage of minor time to major drilling time at the specific prereaming diameter. A HDD pilot project was selected to collect real life data for minor activities durations and major drilling time for prereaming on 12, 22, 26, 36, and 42 in. diameters. Then, the ratio of minor time to major drilling time was modeled. Also, models predicted for the ratio of minor time in HDD project were validated using data collected for the operation to give validation factors of 134%, 123%, 99%, 126%, 142%, and 83% for the reaming diameters 12, 22, 26, 36, and 42 in. respectively.

***Key words**: Drilling time, HDD, Horizontal Directional Drilling, TT, Trenchless Technology, Productivity, Model, Pipe Construction.*

1.0 Introduction

Horizontal Directional Drilling (HDD) is one of the most significant trenchless techniques that HDD technique provides significant benefits for urban environments by decreasing disruption caused by streets excavations [1]. In difficult situations, such as deep pipelines laying or in case of crossing highways, rivers, or lakes, and in crossing airport railways or train tracks or stations, HDD can be not only more cost effective, but also more feasible and applicable than any other trenchless method, such as microtunneling or horizontal auger boring [2].

HDD technique utilizes downhole cutting heads to create a pilot borehole before it is enlarged with back reamers to allow pulling back of a product pipe. Figures 1 through 3 illustrate stages of installation using HDD technique.

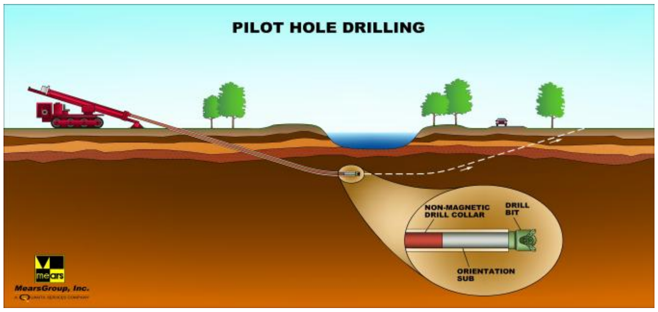

Figure 1: HDD Pilot hole Drilling [3]

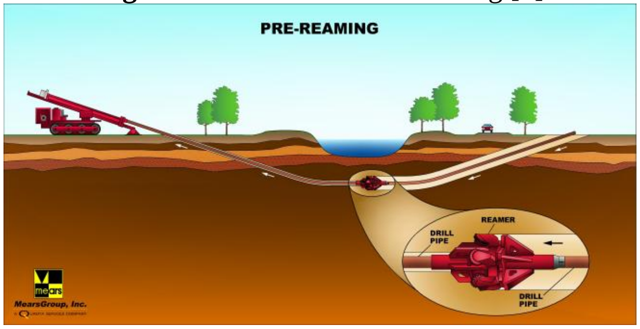

Figure 2: HDD Prereaming Stage [3]

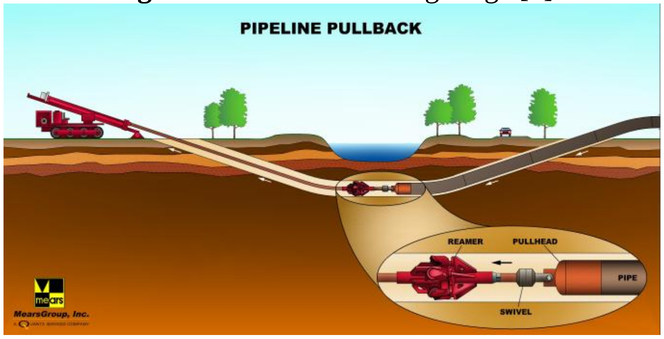

Figure 3: HDD Pullback Stage [3]

The utilization of HDD for the installation of underground infrastructure (i.e., water, oil and gas pipes, telecommunication, power conduits, and in some cases gravity pipes, has shown a rapid growth compared to other trenchless technologies. HDD can install a range of pipe diameters from 2-60 inches utilizing different pipe materials including steel, HDPE, PVC, and ductile iron, with minimum surface and daily life disruptions. Generally, HDD is divided into three main divisions: large-diameter HDD (Maxi-HDD) in the range of 24-60 inches, medium-diameter HDD (Midi-HDD) in the range of 12-24 inches, and small-diameter HDD (Mini-HDD) in the range of 2-12 inches as presented in Table 1.

Table 1: HDD Main Features [4]

Size	Diameter (in.)	Depth (ft)	Length (ft)	Torque (ft-Ib)	Thrust (lb)	Machine Weight (ton)
Max	24–60	≤ 200	≤6,000	≤ 80,000	≤ 100,000	≤ 30
Mid	12–24	≤ 75	≤ 1,000	900–7,000	20,000–100,000	≤ 18
Min	2–12	≤ 15	≤ 600	≤ 950	≤ 20,000	≤ 9

HDD operation goes in cycles to drill the whole bore-path using drilling rods of 32 length. The cycle consists of activities, some considered minors, and one activity considered major which is the time for drilling 32 ft at a specific diameter pass. Minor activities include greasing of HDD drilling rod by worker on the trailer deck, Connecting HDD rod to Backhoe or Hoe, moving HDD rod to HDD machine by Backhoe or Hoe, Connecting HDD rod to HDD machine by worker and HDD operator, building of pressure in HDD machine for motor and drilling fluid, and then drilling of HDD rod distance, to start receiving of a new HDD rod at HDD machine. Figure 4 illustrate the mantling of HDD resources in HDD pilot project, that include HDD machine, HDD drilling rod, trailer, and backhoe. Usually drilling of pilot hole starts at small diameters depending on soil type, and continues at increments in diameters also depending on soil type. Obviously, the increments in soft to medium clayey conditions, sandy conditions, or soft rock are the highest (6-12 in.) between consecutive prereaming diameters. While, in hard clayey conditions, cemented sandy conditions, or medium to hard rock the increments are too low (2-6 in.).

Figure 4: HDD Machine, Backhoe, and HDD Rod on Trailer Deck [2]

Current research aims to introduce HDD operation, resources, activities, analysis of minor time in prereaming operation, ratio of minor time to major prereaming time in HDD project and modeling of relation.

2.0 Background

Horizontal Directional Drilling (HDD) is the most applicable method and cost effective technique that has benefits among trenchless technologies. The records show that HDD has grown rapidly in comparison to other trenchless technology (TT) methods. The 12 HDD operational units in 1984 increased to 2,000 HDD operational units in 1995 [5]. Approximately, 17,800 HDD unites were manufactured and sold during the period between 1992 and 2001 in North America [6]. According to Carpenter on Trenchless Technology Statistics that was accomplished in 2011, 32,135 HDD rigs were manufactured and sold up to the year 2011 as presented in Table 2.

Table 2: HDD Rig Statistics [7]

Year	# of HDD Rigs Manufactured and Sold
1992-2000	16,782
2001 – 2005	5,427
2006 – 2011 (2011 projected)	9,926
Sum of HDD Rigs Manufactured Worldwide	32,135

Drilling using HDD is similar to any engineering operation, starts usually with preconstruction services including surface and subsurface survey or investigation, design, planning, drawings preparation, and specifying of materials to be used in operation [3]. HDD bore path alignment usually continues in different soil conditions within the same project. These changes make the mission of the design engineer difficult when it comes to selecting cutting head, reamer, machine operational conditions including forces, slurry flow rate and slurry mixing ratio. So, considering project conditions, including site findings, soil investigations, and HDD machine abilities help engineers to design and implement HDD operation successfully [8].

Zayed et al. [9] investigated HDD productivity based on two case studies of projects in sandy soils. The first installation was a 1.6-in. diameter polyethylene pipe for a distance of 880-ft, and the second installation was a 2.36-in. diameter HDPE pipe. The data for both cases were used in validating a linear regression relation between cycle time and bore length, resulting, in a productivity rate of 123.4 ft/hr and 88.4 ft/hr, respectively. The results indicated that HDD productivity is a function of soil type, rig size, and pipe diameter. As anticipated, HDD productivity is likely to be degraded in sandy soil when it contains gravel or cobbles. While it may also be anticipated that productivity would decrease with increasing pipe diameter, another conclusion was that HDD productivity is inversely proportional to the diameter of the borehole. A deterministic model for the “major” time was developed to describe the cycle time as given by the following formula: $T_{major} = T_j = T_p + T_r + T_{pb}$, where T_{major} or T_j is the total cycle time for the project; T_p is the pilot hole drilling time, T_r is the reaming time, and T_{pb} is the pull back time.

Also, HDD productivity considering company profile, type of project, duration, product pipe, bidding and estimating practices, and planning and operation control were studied and classified. The most important results of the study are the productivity of HDD (ft/hr) associate to specific pipe diameters presented in Table 3.

Table 3: HDD Productivity vs. Soil Type and Hole Diameter [10]

Diameter Range (in.)	Soil Type		
	Clay	Rock	Sand
2–4	74	42	55
6–8	53	28	41
10–12	42	19	37
>12	28	9.5	27

In another study, investigated HDD productivity in terms of product pipe material, size, and applications were studied also [5]. Similarly, [11] provided HDD productivity rates (ft/hr) in clayey, rocky, and sandy soils, as presented in Table 4.

Table 4: HDD Productivity in Soil Conditions [11]

Reaming Diameter	HDD Productivity (ft/hr) in encountered soil type		
	Clay	Rock	Sand
< 24	180	30–60	180
24–32	150	30	150
>32	120	18	120

3.0 HDD Real Life Data

A HDD pilot project was selected to collect data on minor time and major Drilling time in prereaming operation. The project is located at 360 Hwy at Trinity Boulevard, Fort Worth, TX, USA. The project crosses 360 Hwy by installing a steel pipe 30 in. in diameter for a distance of 1,100 ft to host a 26 in. in diameter ductile iron pipe that was pulled through the steel pipe casing to convey reclaimed water. This pilot project was selected to obtain accurate real-world life data about HDD productivity. Table 5 presents the HDD pilot project specifics and details.

Table 5: Specifics and Details of HDD Pilot Project [2]

Item	Description
Project Name	Village Creek Reclaimed Water Eastern Delivery System
Project Location	360 Hwy, Trinity Boulevard, Fort Worth, Texas, USA
Pipe Type and Diameter	Steel Pipe, 30 in. Outside Diameter (OD)
Reamer Size and Type	36 in. Milled Tooth Reamer
HDD Machine Type	Vermeer D 330 x 500
Crew	HDD Operator, 2 HDD Workers, 1 Mud System Worker, 1 Trackhoe Operator, 1 Oiler and Mechanical, 1 Water Truck Operator, 1 Pump Worker
Length and Depth of Drive	1,100 ft Total Length, & 50 ft Depth at midpoint

Item	Description	
Type of Soil Conditions (starting from exit pit side)	Clayey Conditions (Shaly Clay, Sandy Shale, Shaly Clay, and Silty Clay)	
Preparation Period (days)	4	
Equipment and Tools	HDD Rig, Backhoe, Loader, Forklift, Recycling Unit, Pumps, Trailer & Water Tank	
Overall Productivity (ft/hr)	12 in. Pilot hole	37
	22 in. Prereaming	54
	26 in. Prereaming	91
	36 in. Prereaming	51
	42 in. Prereaming	39
	Pullback	576
Working Area	Machine Side	150 ft x 220 ft
	Product Pipe Side	50 ft x 110 ft
Drilling Fluid Collection Pool Size	35 ft x 35 ft x 5 ft	
Entry Pit Size	18 ft x 20 ft x 6 ft	

Soil was classified as Clayey Conditions, and can be distinguished into Shaly Clay, Sandy Shale, Shaly Clay, and Silty Clay. Data was collected for prereaming operation on 12, 22, 26, 36, and 42 in. prereaming diameter. The data collected presents HDD minor time (t) and HDD major prereaming time (T). Data was collected during site visits for the selected project. Table 6 presents data properties for prereaming diameters used in pilot project in terms of minimum, average, and maximum values for minor time and major drilling or prereaming time.

Table 6: Pre-reaming Data Statistics Properties

Pre-reaming Stage	# of Data Points	Minimum (min.)		Average (min.)		Maximum (min.)	
		Minor Time	Major Time	Minor Time	Major Time	Minor Time	Major Time
12 in.	20	2.33	10.333	4.11	20.257	11.98	47
22 in.	29	1.417	10	1.526	25.31	1.683	65
26 in.	26	1.416	7	1.526	13.148	1.683	37
36 in.	32	1.317	10	1.462	28.593	1.667	72
42 in.	28	1.417	12	1.526	31.04	1.693	102

Minor time presents the summation of durations of activities other than prereaming or drilling time that is considered as major time. Minor time includes greasing of HDD drilling rod (32 ft length) on the trailer deck, connect rod backhoe, move rod to HDD machine, connect rod to HDD machine, and finally building pressure in HDD machine and drilling rod. Major time presents the drilling or prereaming of HDD rod distance for 32 ft distance. Then this operation continues in cycles until drilling finished to the exit point or pit.

4.0 Data Analysis

Analysis of HDD data starts with the calculation of percentage of minor time to major drilling time. The ratio of minor time to major time was modeled with major time as the results section will show later. Model analysis was applied using CurveExpert Professional software for comprehensive data analysis system, version 1.6.5. Seven models were selected to be used in the relation: linear, polynomial 2nd degree, polynomial 3rd degree, exponential, natural logarithm, power, and reciprocal function or model. The acceptance of model is determined on coefficient of correlation (r), coefficient of determination (r^2), standard error, and the 95% of confidence range on model parameters. Modeling results are presented in results section that is coming soon [12].

5.0 Results

After data (% of minor time (t) to main pream time (T) was imported into CurveExpert Professional sheet, analysis was accomplished in terms of data plot, model details, and multiple plot for models on each pream diameter including 12, 22, 26, 36, and 42 in. diameter. Figure 5 presents results of modeling at 12 in. pream time between % of minor time to main pream time and main pream time.

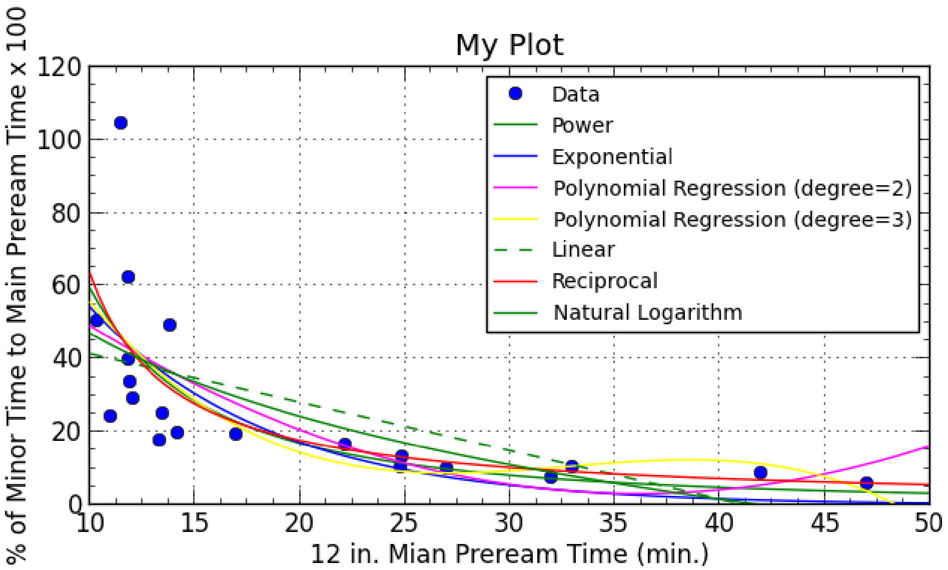

Figure 5: Models Plot for 12 in. Main Preream Time

Table 7 presents details of modeling results for 12 in. prereaming diameter.

Table 7: Summary of Model Results for 12 in. Prereaming Time

Model	Model Equation	Std. Error	R^2	DOF	95% Conf. on Parameters
Power	$t = 3782.8943*T^{-1.80541}$	17.5512	0.4954	18	Yes
Polynomial (3^{rd} Deg.)	$t = 160.862-14.6793*T+0.4617*T^{2}-0.004691*T^{3}$	18.633	0.4945	16	Yes
Reciprocal	$t = 1/(-.024855+0.004068*T)$	17.577	0.494		
Exponential	$t = 170.716*e^{-0.1149*T}$	17.822	0.479	18	Yes
Polynomial (2^{nd} Deg.)	$t = 90.985-4.869*T+0.06747*T^{2}$	18.5903	0.46533	17	Yes
Natural Logarithm	$t = 122.23-32.697*\ln(T)$	18.539	0.437	18	Yes
Linear (1^{st} Deg.)	$t = 54.6412-1.324534*T$	19.649	0.368	18	Yes

And for the 22 in. prereaming stage, Figure 6 illustrates the models plot for the relation between the percentages of minor time to major prereaming time against major time.

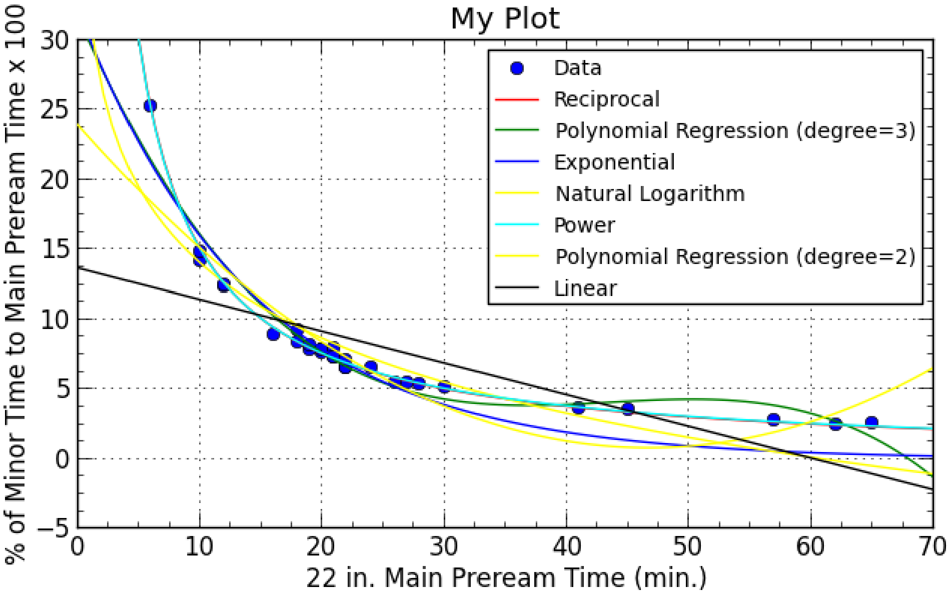

Figure 6: Models Plot for 22 in. Main Preream Diameter

Table 8 presents modeling results of 22 in. prereaming diameter in the HDD pilot project.

Table 8: Summary of Model Results for 22 in. Preream Time

Model	Model Equation	Std. Error	R^2	DOF	95% Conf. on Parameters
Power	$t = 145.416 * T^{-0.986}$	0.35	0. 994	27	Yes
Reciprocal	t =1/(.00063+0.0066*T)	0.3548	0.994	27	Yes
Polynomial (3rd Deg.)	$t = 31.724 - 2.003 * T + 0.00642 * T^2 - 0.000361 * T^3$	1.1477	0. 944	25	Yes
Exponential	$t = 32.204 * e^{-0.0704 * T}$	1.425	0.907	27	Yes
Polynomial (2nd Deg.)	$t = 23.946 - 0.99 * T + 0.0106 * T^2$	1.772	0.861	26	Yes
Natural Logarithm	t = 31.907-7.7574*ln(T)	1.867	0.84	27	Yes
Linear (1st Deg.)	t =13.6984-0.22683*T	3.146	0.546	27	Yes

For 26 in. prereaming is the 3rd stage in this research, Figure 7 presents the models plot for the ratio of minor time to main preream time.

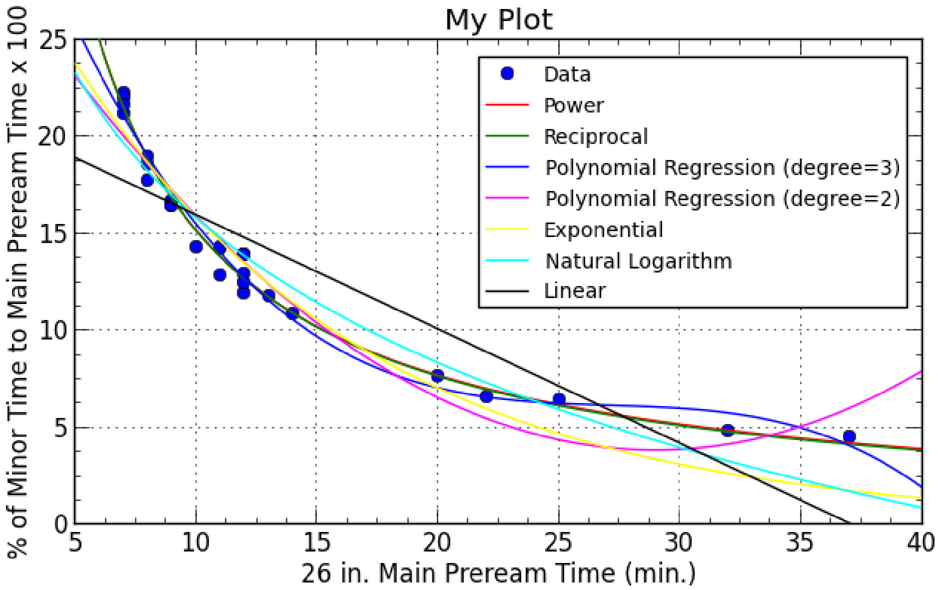

Figure 7: Models Plot for 26 in. Pream Time

Table 9 presents models details for 26 in. pream time between % of minor time to main pream time and main pream time.

Table 9: Summary of Model Results for 26 in. Pream Time

Model	Model Equation	Std. Error	R^2	DOF	95% Conf. on Parameters
Power	t =142.5576*T$^{-0.9735}$	0.5937	0. 9874	24	Yes
Reciprocal	t =1/(.001498+0.006445*T)	0.5975	0.987	24	Yes
Polynomial (3rd Deg.)	t =41.727-3.861*T +0.14114*T^2-0.00174*T^3	0.7861	0. 9797	22	Yes
Polynomial (2nd Deg.)	t = 31.9823-1.4913*T +0.03352*T^2	1.238	0.9475	23	Yes
Exponential	t = 35.666*e$^{-0.08106*T}$	1. 278	0.942	24	Yes
Natural Logarithm	t = 40.608-10.765*ln(T)	1.4115	0.929	24	Yes
Linear (1st Deg.)	t =21.87 -0.589*T	2.503	0.776	24	Yes

For the 36 in. pream main time, figure 8 presents the models plot for the relation between the % of minor time to main pream time and main pream time.

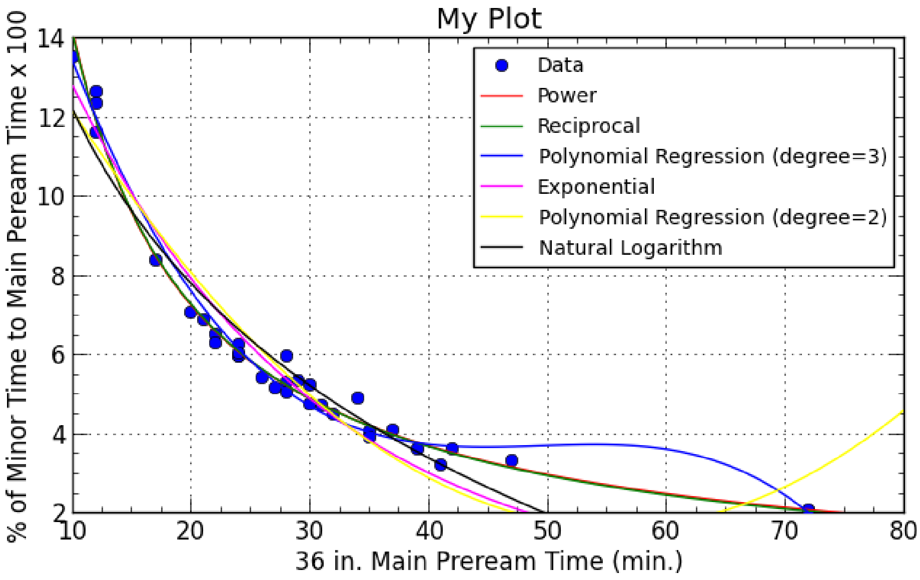

Figure 8: Models Plot for 36 in. Pre ream Time

For the current stage (36 in. pre ream time), Table 10 presents the details of models parameters and values.

Table 10: Summary of Model Results for 36 in. Pre ream Time

Model	Model Equation	Std. Error	R^2	DOF	95% Conf. on Parameters
Reciprocal	t =1/(.0044548+0.006655*T)	0.3163	0.9877	30	Yes
Power	$t = 130.4742*T^{-0.965}$	0.31813	0. 9876	30	Yes
Polynomial (3rd Deg.)	$t = 23.137-1.20305*T +0.02463*T^2-0.00167*T^3$	0.3931	0.9823	28	Yes
Exponential	$t = 20.692*e^{-0.04806*T}$	0.65305	0.9476	30	Yes
Polynomial (2nd Deg.)	$t = 17.23612-0.5591*T +0.00502*T^2$	0.7855	0.9267	29	Yes
Natural Logarithm	t = 26.7773-6.3367*ln(T)	0.8093	0.91945	30	Yes
Linear (1st Deg.)	t =11.564-0.1926*T	1.60754	0.682	30	Yes

And finally, Figure 9 presents the models plot for the 42 in. pre ream diameter.

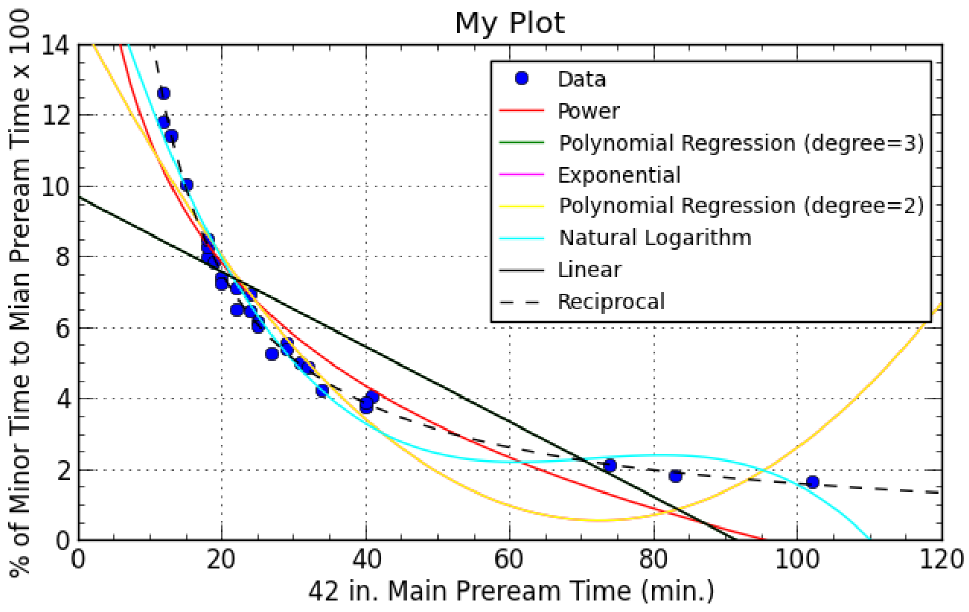

Figure 9: Models Plot for 42 in. Pream Diameter

Table 11 presents details of models parameters and values.

Table 11: Summary of Model Results for 42 in. Pream Time

Model	Model Equation	Std. Error	R^2	DOF	95% Conf. on Parameters
Power	$t = 129.875 * T^{-0.950814}$	0.2573	0. 992	26	Yes
Reciprocal	$t = 1/(.006163+0.006318*T)$	0.25935	0.992	26	Yes
Polynomial (3^{rd} Deg.)	$t = 18.4623-0.71127*T +0.010233*T^2-0.000048*T^3$	0.5491	0.966	24	Yes
Exponential	$t = 18.9247*e^{-0.04332*T}$	0.6976	0.941	26	Yes
Polynomial (2^{nd} Deg.)	$t = 14.8156-0.3936*T +0.002722*T^2$	0.8731	0.911	25	Yes
Natural Logarithm	$t = 22.7379-4.979*\ln(T)$	0.8093	0.897	26	Yes
Linear (1^{st} Deg.)	$t = 9.7147-0.10589*T$	1.6956	0.651	26	Yes

Depending on models' results summary in the Tables 7, 8, 9, 10, and 11 that were previously presented, Table 12 presents the selected models for each stage of 12, 22, 26, 36, and 42 in. prereaming diameters. The proposed models will be useful in predicting ratio of minor time in each cycle or stage in HDD project.

Table 12: Summary of Models at Prereaming Stage

HDD Pre reaming Diameter (in.)	Applied Model	Model Formula
12	Power	$T = 3782.8943*T^{-1.80541}$
22	Power	$t = 145.416*T^{-0.986}$
26	Power	$t = 142.5576*T^{-0.9735}$
36	Reciprocal	$t = 1/(.0044548+0.006655*T)$
42	Power	$t = 129.875*T^{-0.950814}$

6.0 Validation of The Model for HDD Minor Time Ratio (t)

The Validation process for the model predicted for minor time ratio (t) with major prereaming time has been conducted by comparing of results of actual project data with that predicted by applying the models. Table 13 presents Summary for validation of Models for Minor Time Ratio in HDD Prereaming Operation. One case for each prereaming diameter was collected, in addition to one case more for the 36 in. prereaming diameter.

The percentage of difference between actual ratio of minor time and the ratio value calculated by the model presented is calculated by the following equation:

% difference = (Model Productivity – Actual Productivity) / Actual Productivity.

Also the validation factor (VF) is calculated using the following equation:

VF = (Model Percentage / Actual Percentage) x 100%.

Table 13: Validation of Models for Ratio of Minor Time

HDD Pre reaming Diameter (in.)	Major Pream Time (T) (min.)	Actual % of Minor Time (t)	Model Value for (t) %	% Difference	Validation Factor
12	10.626	28	37.707	34.67	134.67
22	9.419	13	15.931	22.55	122.55
26	11.0053	14	13.804	-1.403	98.6
36	19.1861	6	7.568	26.13	126.1
36	8.926	11	15.66	42.37	142.37
42	28.475	6.5	5.378	-17.264	82.74

The validation factors consequently are 134.67%, 122.55%, 98.6%, 126.1%, 142.37%, and 82.74% for the respective prereaming diameter. Then the predicted model can be used to estimate the ratio of minor time in drilling HDD project.

7.0 Conclusions

The estimation of minor time ratio to major prereaming time in HDD project deserves studying and research as this time proportion is part of the total cycle time and so total project time. The current study is an efficient step in this operation. The aims of this study were implemented; introducing HDD operation for readers, researchers, and academics, then predicting of valid models for ratio of minor time to major prereaming time in HDD project. The most critical issue in this research according to the author is to find enough data for the research material to continue modeling and validation in the same manner for other projects and HDD operations.

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Biography

Mohmd Kh. Sarireh is an assistant professor in Civil Engineering Department, Tafila Technical University. He received his B.Sc. in civil engineering from Mu'ta University, Jordan, and he received his M.Sc. in Civil Engineering from The University of Jordan, Jordan. He got his Ph.D. in Construction Engineering from Civil Engineering Department at The University of Texas at Arlington in August 2011, Arlington, Texas, USA. His Ph.D. Thesis was in modeling of productivity for horizontal directional drilling and factors affecting HDD productivity.

The author had published the following researches and papers in the following reputable journals around the world:

1. The Fourth International Conference on Pipelines and Trenchless Technology hosted by China University of Geosciences (Wuhan), American Society of Civil Engineers, and the University of Texas at Arlington (UTA) that was held in Xi'an China on October 16-18/2012. "The Productivity Analysis of Horizontal Directional Drilling – A Case Study," Sarireh, M., Najafi, M., Slavin, L., and Jain, A. (2012) Case Study of Productivity Analysis for Horizontal Directional Drilling. Pipelines 2012: pp. 857-868.
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