

A glimpse of horizontal directional drilling productivity factors

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Abstract. Horizontal Directional Drilling (HDD) is a trenchless technology provides an installation alternative that offers a lot of benefit compared to traditional open-cut method. It's called HDD because its steering ability to avoid existing utilities or other obstacles either horizontally, vertically and even pulled back where she got its name. HDD was developed in California in the 1970s and was introduced in Europe in 1986. Since year 1992 up to 2016 there are about 40 thousand unit HDD machine were sold worldwide. Contractors, consultants, municipalities and decision makers are always in difficulties to determine the installation cost and the duration required when using the HDD method due to the presence of many qualitative factors. Understanding the HDD productivity factors will assist the stakeholders to overcome this matter. The aims of this study are to identify the existing HDD productivity factors, identify the factors that affect HDD productivity, identify the current tools that are used by current researcher, and identify the open problems and areas related to HDD productivity for improvement. Systematic Literature Review (SLR) was carried to previous related papers retrieved by a manual search, critically analysed and discussed. Researches regarding HDD productivity conducted by previous researchers were compared and discussed. The studies involved journal articles, conference papers, books, guidelines and etc. Consequently, these previous experiences and models can assist the contractors, consultants, municipalities and decision makers in preparing their costing and scheduling. The lacking factors on HDD productivity factors were highlighted and suggested for futre studies.

1 Background

Horizontal Directional Drilling (HDD) is a trenchless technology that provides an installation alternative that offers a lot of benefit compared to traditional open-cut method.

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According to Najafi, this method is called HDD because of its steering ability to avoid existing utilities or other obstacles either horizontally, vertically and even pulled back. [1]. Bayer quoted HDD was first started in California in the 1971 and was introduced in Europe in 1986 [2]. Sarireh had concluded although the first HDD river crossing across Pajaro river near Watsonville, California was carried out in 1971 only 36 successful crossings were completed until year 1979 [3]. For the first two decades the technology which was formally very difficult to operate/manage had evolved significantly to what we have today which is user friendly, well equip with hydraulics system, power source, drill frame, drilling fluids and detection guidance systems [4]. Most research on horizontal directional drilling (HDD) that conducted in the past are either concentrating more on how to improve the drilling technology, plants, tools, to make it more user friendly, easy guided, conducting experiments in developing better work procedures, user friendly guided plant, to enhance the work process, minimise possible risks, to improve on quality, to widen the HDD usage to other sectors, stability of boreholes, bentonite effect, utilities, lawsuit issues and etc. Carpenter had conducted HDD survey market and found out that from year 1992 up to 2016 more than 44 thousand unit HDD rigs were sold worldwide [5][6][7].

Willoughby added HDD method offers less disturbance to traffics, the public, business activities and neighbourhood, lower restoration cost, less noise, dust and minimum import/export of the construction materials make this method very useful for works within urban and sub-urban areas. In addition this method also uses to drill through congested utilities areas with minimum cutting and with minimum impact to the environment [8]. Allouche informed that HDD method can also be used for horizontal sampling where it uses to collect contaminated sampling at contaminated ground [9].

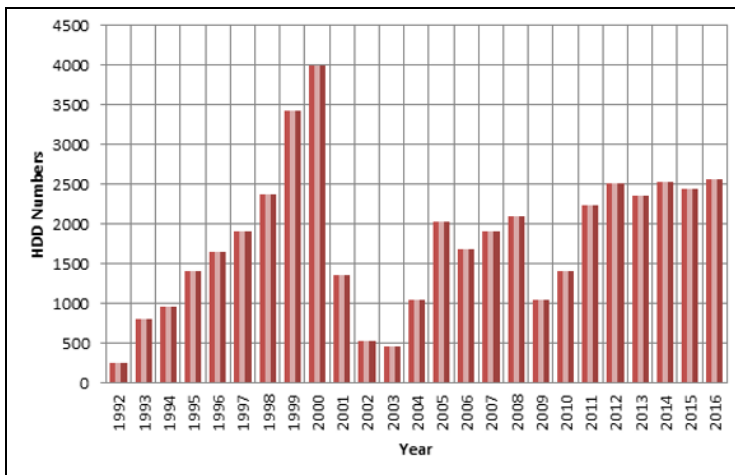


Fig. 1. HDD Plant Manufactured and Sold Worldwide [5][6][7].

The increase of HDD usage reached its phenomenal growth, with only 12 operational unit in 1984, the numbers had increased drastically to more than 2,000 units in 1995 with a multiplying factor up to 167 times just within a decade. Since then the sales of HDD machines consistently increases about 2,000 plants a year except during 1999 and 2000 where telecommunication sectors in US reach its boom.

Figure 1 and Table 1 shows number of HDD plant manufactured worldwide from 1992 to 2016. Until 2016 about 45 thousand HDD machines have been sold. Meanwhile in Figure 2, the pie chart shows the USA HDD markets according to sectors.

Table 1. HDD Rigs Manufactured and Sold Worldwide [5][6][7].

Year	Number of HDD Rigs Manufactured/Sold
1992–1995	3, 435
1996–2000	13, 347
2001–2005	5, 427
2006–2010	8, 154
2011–2016 (2016 projected)	14, 462
Total HDD Rigs Manufactured Worldwide	44, 825

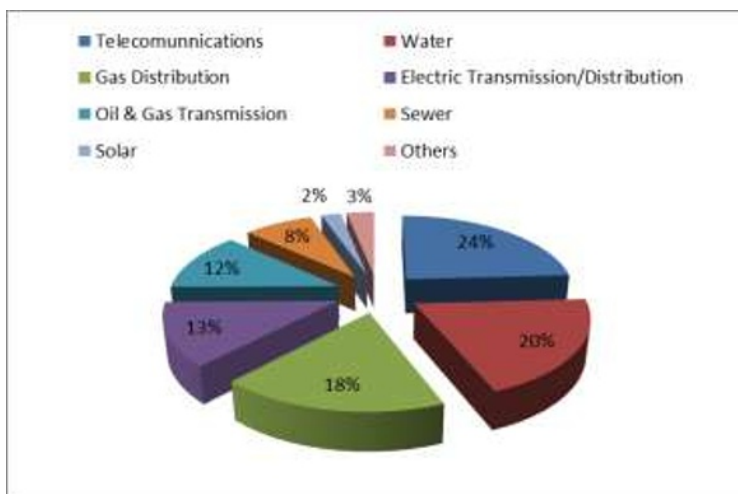


Fig. 2: HDD Market in USA 2016 According to Sectors [7].

As illustrated in Figure 3, HDD construction process starting with piloting a small pilot hole using a pilot head along the desired centre line of the proposed profile, followed with back reaming until the required drilled trench size to house the utility pipe, preparation of the product pipes and finally the pulling of pipes into the bored hole. Its major components are the drilling rig, drill pipes, slurry/bentonite, slurry recycling, survey equipment, drill bits, reamers and pipeline materials [10]. A transducer sonde is attached at behind of the cutter head during piloting and the signal is collecting by a locator carry by a person (tracker) that walk on top of the HDD alignment. The HDD operator will communicate with the tracker in order to control the pilot head drilling path. Ariaratnam quoted that until 2016, USA is still becoming world no 1 HDD machine manufacture followed by China and India [11].

In the past contractors always use their past experiences in estimating HDD production rates when participating in a tender exercises due to lacks of models that can predict productivity of the trenchless techniques. This also goes to the consultants, municipalities and decision makers when they need to determine the installation cost and the time frame of using the HDD method. This task will never be easy as the HDD process comprises a lot of factors to be considered in its productivity prediction and cost estimation.

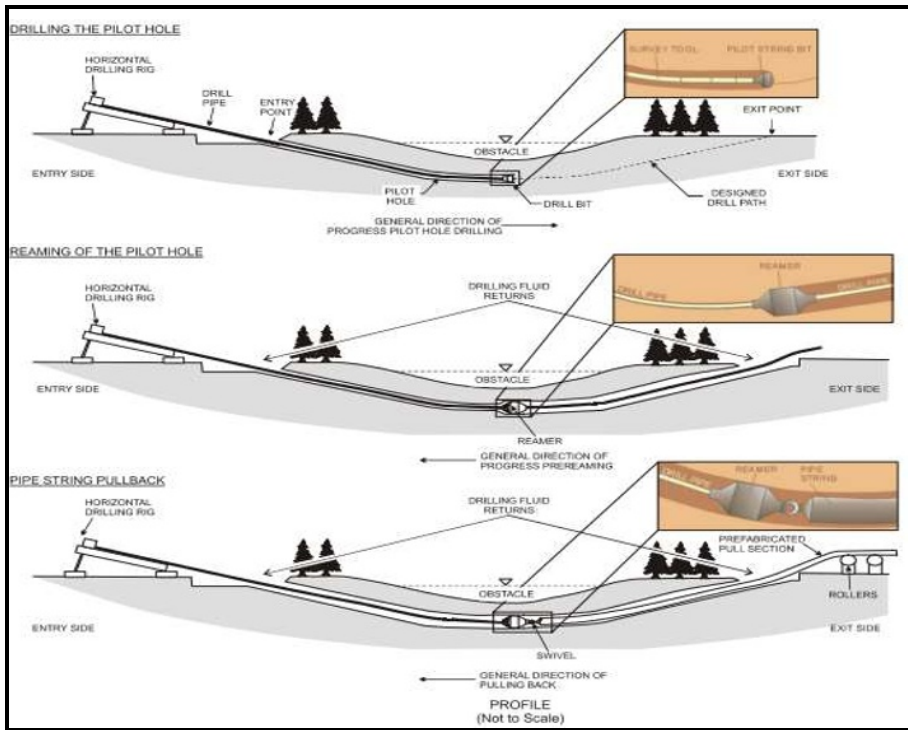


Fig. 3: HDD Process [10].

2 Objective

Contractors, consultants, municipalities and decision makers are always in difficulties to determine the installation cost and the duration required when using the HDD method due to the presence of many qualitative factors. Understanding the HDD productivity factors will assist the stakeholders to overcome this matter. The aims of this study are to identify the existing HDD productivity factors, identify the factors that affect HDD productivity, identify the current tools that are used by current researchers, and identify the open problems and areas related to HDD productivity for improvement.

3 HDD Productivity Factors

Similar to the definition of project management by PMBOK that a project is unique, not a routine operation, but a specific set of operations designed to accomplish a singular goal, it also goes to HDD project completion [12].

Sarireh defined HDD rig productivity as the distance drilled, prereamed, or pulled back by HDD machine during a unit of time, denoted as (ft/hr) or (ft/day). Measuring productivity on hourly basis is more accurate than on daily basis. An hourly record allows considering subsurface conditions and changes as well as machine and worker efficiency in different time periods during operation [13].

Ali had concluded HDD works are affected by multiple and interrelated three major productivity factor which are management condition, physical conditions and environment condition. This make HDD operation more critical and specific [14]. Royal had arised that one HDD profile usually continues in different soil conditions. Drilling in various type of

soil makes the design engineer difficult in selecting the suitable cutting head, reamer, machine operational conditions including forces, slurry flow rate and mixing ratio. Therefore, considering project conditions, including soil investigations, and HDD machine abilities help engineers to design and implement HDD operation successfully [15].

Project Management Body of Knowledge affirmed every project shall going through its project life cycle. Each stages starting with initiation, planning, execution and closing have its own related processes to be done in order for the project to be completed and closed [12]. Najafi 2010 noted, installation using HDD method also similar to any other construction project, starts with pre-construction planning including surface and subsurface survey, drawings preparation, product pipe specification, HDD profiles design, selection of HDD machine and team, works planning, inspection and construction monitoring [1].

Najafi (2013) stated that the duration for HDD project are varies from one to another and very much depending on many factors such as contractor and operator experiences, project surface and sub-surface conditions, equipment used, type of application, degree of planning and pre-planning of the project [16]. According to Allouche, similar to other type of construction works, productivity is the key to profitable operation [17].

The productivity of HDD operation is very critical for contractors, engineers, and machine operators, also very important for owners and pipelines operators. According to the HDD operation conditions, contractor and/or engineer decide to select the size of HDD machine suitable to the type of soil encountered and the size of job. There are several challenges associated with HDD in marine environment and river installations. These challenges include construction restrictions such as mud control, expected frac-out, limited working area, seasonal restriction for aquatic habitats, and minimising of disturbance for wet lands in project site and other adjacent sites expected to be affected. To prevent frac-out problems, lower pressure should be utilised and deep lay down of pipeline should be applied in alignment selection. An emergency plan must be in place if frac-out expected to happen. Also, casing is usually required for product pipe. Effective construction management will improve site accessibility and provision for material storage and fabrication [13].

In the past contractors, consultants, municipalities and decision makers are always in difficulties to determine the duration and installation cost via HDD method due to the presence of many qualitative factors. The HDD process comprises a lot of factors to be considered in its productivity prediction and cost estimation. Thus the development of HDD productivity model will help to meet the industrial essentials. Ali had concluded that in the past the productivity of trenchless technology methods is usually predicted using exploratory techniques and experts opinions without considering the subjective factors effect. In addition, the industry lacks of HDD productivity models that can estimate productivity of the HDD works [18].

Table 2. HDD Pre-reaming Productivity (ft./hr.) vs. Soil Type and Bore Diameter [8].

Bore Diameter (in)	Soil Type		
	Clay	Rock	Sand
< 24	180	30-60	180
24 - 32	150	30	150
>32	120	18	120

Willoughby had provided HDD pre-ream productivity rates (ft./hr.) in clayey, rocky, and sandy soils, as presented in Table 2 [8]. He also confirmed that compared rocky

conditions, sandy and clayey soils allow much higher productivity rates, for all reamed/borehole diameters. With the installation of utilities using HDD method within urban and sub-urban areas becoming more famous this method may prone to accidents if it is not carried out properly and its productivity may also affected.

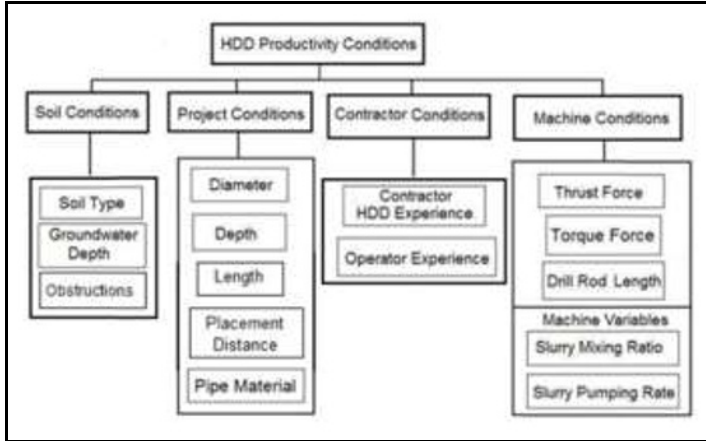


Fig. 4. HDD Conditions Affecting Productivity concluded by Sarireh [19].

Figure 4, is the illustration of HDD Productivity factors as concluded by Sarireh, consists of four HDD productivity factors namely soil conditions, project conditions, contractor conditions and machine conditions and their sub-factors [20].

Research on the factors that affect HDD methods and its construction progress rate has gained more attention since last decade. Zayed concluded this is because the productivity prediction model for HDD in the pre-construction phase will help municipalities, contractors, consultants and infrastructure professionals to do their estimation and costing [21]. In relevant development Najafi stated that HDD productivity depends on many factors such as (1) soil conditions; (2) project conditions; (3) contractor conditions; (4) machine conditions; (5) machine variables [16]. Some other authors and researchers had slightly different opinions on the factors used. But all these factors would have a significant effect on HDD productivity.

4 Method

Systematic Literature Review (SLR) was carried out on previous related papers retrieved by a manual search, critically analysed and discussed. Researches regarding HDD productivity conducted by Allouche et al. [17], Zayed et al. [22], Ali, Zayed & Hegab [18], Adel & Zayed [23], Sarireh et al. [24] [25], and Zayed & Mahmoud [21] [26] were compared and discussed.

5 Results and Discussion

The studies involved the reading of journal articles, conference papers, books, reports, guidelines and etc. Consequently, HDD productivity factors were identified and analysed.

Allouche's studies were concentrated on a literature review of the trenchless past researches and surveys that were conducted among the local contractors and utility companies in the US and Canada. His surveys involved questionnaires, site interviews, site visits, direct data collection and telephone calls distributed among the experienced contractors.

Contractors were required to identify the average productivity rate based on an 8 hour per day. Considering company profile, type of project, duration, product pipes, bidding and estimating practices, and planning and operation control as HDD productivity factors [17].

He concluded that HDD productivity tends to decrease with the product diameter increases, drilling in clay and silt clay gives highest productivity, lower productivity is expected while drilling in cobble and gravel and average rates are expected for sand. He also concluded that the most important results of the study was the productivity rate of HDD (ft./hr.) as a function of pipe diameter and soil type, (i.e., clayey, rocky, sandy), as presented in Table 3 below. Eight scenarios were concluded as the typical problem faced by HDD activities e.g. loss of circulation, inclement weather, tracking device, buried obstacles, breakdown of drill, cave in of borehole, bending of rods and voids in the ground [17].

Table 3. HDD Productivity (ft./hr.) vs. Soil Type and Pipe Diameter [17].

Pipe Diameter (in)	Ground Conditions		
	Clay	Bedrock	Sand
2-4	74	43	55
6-8	53	28	41
10-12	42	19	37
>12	28	9.5	27

Zayed developed two regression linear models that designed between cycle time and bore length. The productivity factors were considered are stated in Table 8. Validation of developed model were carried by using 2 case studies (soil type sand). On the first validation having pipe diameter 40 mm, bore length 880 ft, the calculated and actual productivity is 123.4 L-ft/hr & 117.33 L-ft/hr respectively with VF = 1.052. For the second validation, for pipe diameter 60 mm, bore length 495 ft, the calculated & actual productivity is 88.4 L-ft/hr and 82.5 L-ft/hr respectively VF = 1.071. Both result near to 1.0. According to the authors, the most crucial consideration for HDD productivity was found to be contractor’s skills & expertise and geological conditions of the soil. Further research in this direction is needed by considering more factors affecting productivity [22].

According to Ali usually heuristic techniques and expert opinions were used to predict trenchless techniques (TT) progress as most of their productivity factors are subjective. Therefore these complexity had made the productivity assessment process difficult especially with the lacking productivity models that can predict of trenchless techniques progress. Two main steps for TT productivity estimation are assessment of the effect of subjective factors on productivity and how it can be quantified and quantitative factor assessment (i.e. duration of activities, labor, equipment rates, etc.) [18].

Ali have developed a methodology for calculating the Productivity Index (PI) in order to represent the subjective effect in refining productivity assessment. The proposed PI model was developed using analytic hierarchy process (AHP) and Fuzzy Logic (FL) based on 12 productivity factors categorised under three main categories as shown in Table 8. Results of the designed model and the developed automated tool are compared to the results of the test data set to check their reliability in assessing the PI value. The efficiency of each reply is collected from the questionnaire sent to reviewers. They are asked to provide information (i.e., efficiency, etc.) for an average project. The designed tool demonstrates its robustness in assessing the PI value for microtunneling and HDD projects are 95.10 and

87.36%, respectively. Due to the limitation of data collected, the developed models are limited to new HDD and Micro-tunneling operations, in only clay and sand soils only. These reliability percents are reasonable and acceptable to test the model developed. It is recommended to increase the test data set in order to validate the results of the model developed. This research is relevant to both industry practitioners and researchers. It provides practitioners with a model that justifies their productivity calculation by quantifying subjective factor effects. This will affect their schedule and cost estimation for trenchless projects. In addition, it provides researchers with the factors that contribute to productivity of TT methods, the development methodology for the PI model, and the automated tool that can be used in similar research applications [18].

On the other hand Adel concluded HDD productivity factors were classified into managing environmental conditions, pipe mechanical condition and soil type and their productivity factors as per Table 8. Neurofuzzy productivity prediction model for pipe installation in clay soils were developed. The study was focus on both the quantitative and qualitative factors affecting productivity calculation. The collected data are clustered according to the eight input parameters with only clay soil type was considered. The questionnaires used are designed based from literature review and interviewing of the industrial stake holders. First part was on project information and the second one collects the effect of various factors on productivity using unified fuzzy performance scale. The developed model is tested after the modelling phase, where the neurofuzzy system, splits the modelling data into training and testing data. Eight of the total collected data points are unexposed to the neurofuzzy system during the training phase to be used for testing purposes. Afterwards, the testing data set is used to predict productivity and compare results with the real time productivity in which it showed robust results with an average validation of 96% [23].

Due to HDD competitive market conditions, client expectations, and technological advancements, an emergent need for HDD contractors has risen to identify the major factors that affect the HDD productivity. There is insufficient information in the literature regarding models and software for the HDD productivity analysis. Therefore, a productivity prediction model for HDD projects was developed using the neurofuzzy system. The model helped experts to estimate and predict the project duration. It is found that crew and operator skills, soil type and pipe diameter were the most significant factors affecting HDD productivity, while pipe length and weather conditions had the least effect. This model was a tool for experts and professionals to help them justify their productivity calculation by quantifying some of the subjective factors effect. This will better impact their schedule and cost estimation of HDD works. Moreover, it provides researchers and experts with the most significant factors that contribute to HDD installations. The developed neurofuzzy methodology and model can be used in similar research applications [23].

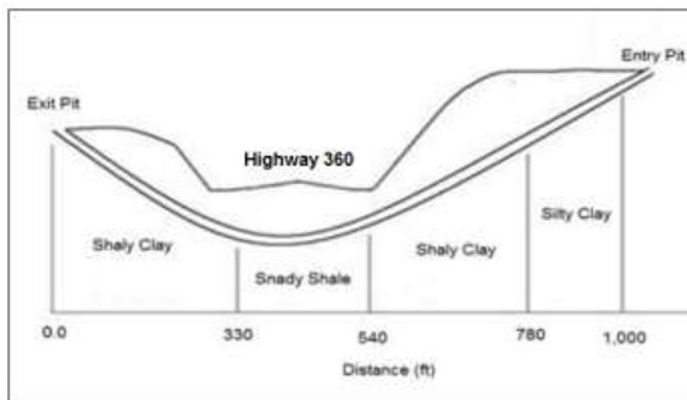


Fig. 5. Bore-path P Profile for HDD Pilot P Project [23].

Sarireh conducted a case study for a 30 inch diameter steel pipe HDD crossing Highway 360 at Trinity Boulevard, Fort Worth, TX, USA. HDD productivity factors mentioned in Figure 5 were adopted. This HDD profile ran a cross various type of soils. In this case study, only the soil and project (reaming diameter) variables are considered for the purpose of determining HDD productivity with respect to these parameters. Other HDD productivity factors (contractor and machine) are considered constant, and will be the subject of a future study. It is generally understood that soil conditions and drilling (reaming) diameter are the most critical conditions affecting HDD productivity. These conditions determine most of required features of the HDD rig, including size (e.g., thrust, torque) and type of equipment, and tools (reamers) [24].

This particular site and application was selected as appropriate for obtaining accurate real-data, to determine variations in HDD productivity due to the changes in soil and project conditions. Table 4 indicates the results from the pilot project. HDD operations are divided into three main stages: pilot borehole drilling, reaming, and pullback of product pipe. In this case study, productivity data were emphasis on the reaming stage, which is the most time intensive phase of the whole HDD process [24].

Table 4. Values of HDD Productivity (ft/hr) During Reaming in the Case Study Project [24].

Soil Conditions	Reaming Diameters (in.)				Average
	22	26	36	42	
Shaly Clay I	127	185	82	134	132
Sandy Shale	154	100	54	59	92
Shaly Clay II	107	193	63	83	112
Silty Clay	52	230	114	76	118
Average Productivity	117	168	75	95	114

The soil in the pilot project was initially described as clayey soil, but subsequent geotechnical investigations indicated the four distinct soil formations as shown in Figure 5. Several pre-reaming operations were required to achieve the final desired borehole diameter. Thus, the borehole was enlarged using 22, 26, 36, and 42 inch reamers (up to 140% of the product diameter) [24]. In general, the observed relative productivity rates are consistent with expectations based on the incremental diameters. Several conclusions were made from this study;

- HDD productivity is adversely proportioned to the pre-ream diameter.

- HDD productivity is higher at the start and end of the borehole; this means that the soil conditions are a controlling factor on HDD productivity.
- The effects of depth of borehole is not clear as the soil conditions change at different depths and the HDD rig operator can accommodate the changes in soil conditions by increasing the HDD machine operational thrust and torque values [25].

Zayed conducted some data collection and analysis, a thorough literature review related to the factors that affect productivity for HDD works and previous HDD productivity models as well as neurofuzzy and AHP modeling techniques. A new automated HDD productivity prediction model is developed followed by model validation and sensitivity analysis [21]. The HDD productivity model development and validation were presented in a second companion paper [26]. This study is focused on both quantitative and qualitative factors affecting productivity calculation. Due to lack of HDD productivity studies, a thorough literature review is performed on Horizontal Earth Boring (HEB) techniques and HDD productivity. Based on literature review and industry experts, 13 main factors are identified as being the most significant factors affecting HDD productivity as tabulated in Table 8. Trenchless technology contractors in Canada and USA are contacted to obtain data from real HDD projects through questionnaires, site interviews, telephone calls, and emails. Approximately, 220 questionnaires were sent to TT professionals in North America with a response rate of 12% (28 projects) [21].

Questionnaires in hard and soft or online copies were distributed and collected from HDD contractors, consultants, field technicians and individual experts in North America. By analyzing pipe diameter and its relation with the calculated on site productivity, it is found that the larger the diameter, the lower the productivity due to the need of multi-reaming process. The collected data was limited to only utilizing medium and large size rigs. Data analysis showed that medium and large size rigs represent 68% and 32% of collected data, respectively. Experts indicated that HDD industry is dominated by medium rigs as dictated by the need to increase production rates and due to project size and environment. The small drilling bit capabilities have a decent market however, it was not involved in this study due to data limitations. The collected data on HDD projects indicated that 82% of HDD operations in clay utilised medium size rigs and 18% utilised large size rigs, while 75% of HDD projects in rock utilised large size rigs and 25% only utilised medium size. In addition, all the collected HDD projects in sand soil utilised medium size rigs. The current research studied a wide range of pipe lengths, which varied from 84 to 2300 m [21].

The purpose of establishing factor ranking is to highlight the relative importance of HDD productivity factors and tabulated in Table 5. This study had reduced from 13 productivity factors to only 8. Some factors were merged [21] and some are eliminated as their effect are low e.g. pipe type and pipe depth [27].

Table 5. The weight (Wi) of revised list of factors [21].

Rank	HDD productivity investigated factors	Weight (Wi)
1	Operator and crew skills	0.1558
2	Soil type	0.1503
3	Pipe diameter	0.1377
4	Drilling bit capabilities	0.1331
5	Machine condition Steering problems, Slurry flow rate)	0.1263
6	Unseen obstacles	0.1068
7	Pipe length	0.0966
	Site/weather conditions (Safety	

8	Regulation)	0.0934
	Total	1.0000

Three main case study projects were selected to implement the developed model operating through clay, sand, and rock soils and the details as per mentioned in Table. 6.

It is found that crew and operator skills, soil type, and pipe diameter are the most significant factors affecting HDD productivity while pipe length and weather conditions had the least effect. The identified factors assist experts and professionals to justify their productivity calculation by quantifying some of the subjective factors effect. This will better impact their schedule and cost estimation of HDD works. Moreover, current study provided researchers and experts with the most significant factors that contribute to HDD installations [21].

Table 6. Information on Case Study Projects [26].

Project information	Project 1: Rock case study duration (min)	Project 2: Sand case study duration (min)	Project 3: Sand case study duration (min)
Location	Saint Lazarre, Montreal West, Quebec, Canada	Seaway, Longueuil/ Notre-Dame, Quebec, Canada	Connecticut, USA
Soil type	Clay	Rock	Sand
Diameter (mm)	200	140	102
Length (m)	300	440	660
Drilling rig size	Medium	Large	Medium
Operator and crew	Highly skilled	Highly skilled	Highly skilled
Machine conditions	Moderate	Very good	Moderate
Expectation of unseen buried obstacles	Moderate	Low	High
Site, weather, and safety conditions	Moderate	Bad	Good
Productivity (m/h)	15.65	10.67	11.43
Calculated productivity (m/h)	13.67	9.47	10.21
Precision (%)	87.34	88.75	89.33

Table. 7 shows the duration ofHDD activities in the three case study projects, i.e., for clay, rock, and sandy soils.

Table 7. Average Activity Duration [26].

Drilling activity	Project 1: Clay case study duration (min)	Project 2: Rock case study duration (min)	Project 3: Sand case study duration (min)
Major			
Site preparation (SP)	45	180	600
Pilot hole drilling (PH)	210	180	960
Reaming (R)	210	0	720
Pipe pullback (PP)	30	120	360
Auxiliary			
Pipe connection and layout	430	1,140	600
Angle adjustment	15	15	60
Drill pipe segment joining	30	90	360
Attaching reamer/shackle	30	120	60
Pipe swivel assembly	30	270	60
Tracking activities	60	180	60
All assessment activities	60	180	120

Zayed developed HDD productivity prediction models using a NF approach. Three types of soil are considered, i.e., clay, rock, and sand. Data are collected from three case study projects to validate the concept of the developed models and show their precision. The average precision percentage for the developed models is 88.47%, which shows robust results [26].

Mostly the HDD productivity was calculated either based from the actual scenario, case study, using linear modelling, and neurofuzzy model. Some of the models were validated using actual case study. It is found that crew and operator skills, soil type, and pipe diameter are the most significant factors affecting HDD productivity while pipe length and weather conditions had the least effect. These identified factors will able to assist experts and professionals to justify their productivity calculation by quantifying some of the subjective factors effect. Zayed believes this will better impact their schedule and cost estimation of HDD works [21].

The productivity factors stated in each study are summarised in Table 8. The evolution of HDD productivity factors is started with only two factors which is sub-surface conditions and pipe diameter and later its reached five major factors namely contractor conditions, project conditions, machine conditions, machine variables and soil conditions with some sub-factors.

Table 8. Summary of HDD Productivity Factors.

Allouche et al.(2000) [17]	Zayed et al. (2007) [22]	Ali, Zayed & Hegab (2007) [18]	Adel & Zayed (2009) [23]	(Sarireh et al., 2012; Sarireh et al., 2013) [24][25]	(Zayed & Mahmoud, 2013; Zayed & Mahmoud, 2014) [21][26]
Subsurface conditions Pipe diameter	Job and mgmt. conditions Operator skills Pipe dia. and material etc. Rig Size Soil Type Site conditions Weather	Management Conditions -Managerial skills -Operator’s efficiency -Safety Reg. -Mechanical cond. Physical Conditions - Pipe size - Pipe length - Pipe usage - Pipe depth Environ. Conditions - Unseen soil cond. - Water table level - Soil cond. - Site cond.	Managing Env. Cond. -Rig Size -Buried Obstacles -Site weather -Operator & crew skill Pipe Mech. Cond. -Length -Diameter -Machine Soil Type -Clay -Sand -Rock	Contractor Conditions -Cont. Experience -Operator Exp. Project Conditions -Diameter -Depth -Length -Placement Distance -Pipe Material Machine Conditions -Trust Force -Torque Force -Drill Rod Length Machine Variables -Slurry Mix Ratio -Slurry Pump Rat Soil Conditions -Soil Type -Ground Water -Obstructions	Management Conditions -Crew/operator skill -Rig size/drill bit Mechanical Conditions Machine Condition -Slurry Flow Rate -Steering Problem Pipe Conditions -Pipe diameter -Pipe Length -Pipe Depth (eliminated) -Pipe Type (eliminated) Environmental Conditions -Soil Type -Unseen buried obstacles -Site/Weather & Safety Conditions

The arising of HDD Machine from China though its can reduce the construction cost (cheaper) it may also invites HDD sub-contractors with lacking of HDD knowledge and training to join the market. Moreover the rapid growth in using HDD drills method within urban and sub-urban areas becoming more famous in the last two decade make some areas are almost saturated with utilities and any activities by inexperienced HDD contractors can invite catastrophic. If no action taken to avoid these from happening, what have been faced by HDD market in USA in early 90s, where accidents and failures related to HDD method becoming a big issue. Bennett stated, back then HDD market was exploding due to rapid growth in constructing fibre-optic backbone across the United States. Unfortunately, this fast grown technique caused insufficient experienced drillers, locator, inadequate geotechnical investigations and a lack of established good practices. In 1998, concern about potential damages from HDD installations beneath its roadways the California Department of Transportation (Caltrans) imposed regulations requiring training for HDD contractors when drilling under the state lands [28].

Similar concerns were being raised around USA by other transportation and environmental agencies. Agencies, such as Santa Clara County, considered declaring a moratorium on all drilling operations until a standardised set of practices was established and training of operators was implemented [28]. In addition poor drilling practices by some contractors have caused utility strikes that have resulted in major legal ramifications and subsequent negative image of the technique. Willoughby added the damage claims are normally huge as it is not only the utility repairing cost but also include “loss of revenue” where insurance company are normally not covered [8]. This concern should be taking seriously with the increase of damaged caused by HDD activities e.g. the damage of fibre optic cables connected to Custom Malaysia Information System in Klang in May 2016, that had affected Westport operation [29] and the power outage in Menggelebu district in Ipoh, Perak where 138 sub-station were down [30] both incidents where fibre optic and power cable were stroke by HDD activities. Similarly in 2016, American Gas Association had conducted a white paper report regarding four (4) gas pipeline stroke by HDD activities in New Albany, Indiana (November 8, 2011), in Kansas City, Missouri (February 19, 2013), in Royal Oak, Michigan (February 27, 2013) and in Ewing, New Jersey (March 4, 2014) [31].

6 Conclusions

Most studies considered only three types of soil namely clay sand and rock or less. Therefore there are still some room to carry out the studies to the next level. Majorities also agree that crew and operator skills are the most significant factors affecting HDD productivity. This review provides researchers with some guidelines for future research on this topic. It also provides broad information on HDD productivity factors that could be useful to HDD stakeholders.

Based on the results gather from these researches, the contractors, consultants, municipalities and decision makers are now have an options to do their costing and scheduling for the HDD works either using the estimated HDD productivities from the past experiences/studies or to use HDD productivities model that have been developed.

Zayed concluded his study provided researchers and experts with sound models that contribute to HDD productivity and installations. It will also be helpful the contractors, consultants, and HDD professionals in predicting execution time and estimating the costs of HDD projects during the preconstruction phase.[26].

Several rigorous researches have been carried out in order to provide HDD productivity factors, however there are still some lacking in current HDD productivity factors especially when a lot of utilities founded were struck by HDD activities.

Most researchers had combine the utilities detection and other obstructions/obstacles under one item. With the accidents of hitting buried utilities are getting higher and higher especially within the sub-urban/urban areas, this will impact the HDD productivity badly if the utilities detection is not carried properly and throughly. Therefore in future studies the author would like to propose for obstructions/obstacles and buried utilities sub-factors to be separated and make them as two independent sub-factors for the HDD productivities factors. This will able to differentiate the effect of other alien buried obstacles compared to the buried utilities and would able the provide stake holders a better estimation. Most of the developed models mostly only considered three soil types, the investigation of more soil types and the calculation of HDD productivity in these soil types must be subject to more customized data collection and will be the subject of future research [26]. In addition to make the developed model becoming more robust it also suggested for more case studies were conducted a cross the worls.

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