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Research Paper

After Effect of Pump Supply Disruption

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Abstract

The aim of this study is to investigate on the after effect of pump supply disruption in ground water irrigation in Northern Ethiopia. A survey is conducted in 16 sample drilled wells (DWs) to reveal the losses because of supply delay. Failure is inevitable and the failure of a submersible pump, critical equipment in irrigation infrastructure, is considerably high according to the survey. Moreover, the downtime delay is the aggregation of purchasing order process delay, transportation delay and replacement/installation delay. Discrete time probability distribution function is used to estimate the economic loss of the aftereffect by determining the cost, production volume and profit of the irrigation business using triangular probability distribution functions. The downtime is analyzed under the discrete time of 1 week downtime, 2 weeks downtime, 3 weeks downtime, and greater than 3 weeks downtime horizon. Finally, the study ascertains that downtime in ground water irrigation results in sizable economic losses like yield loss, total vegetables/crops loss, and opportunity cost. When the downtime duration extends, the loss upturns radically. For instance, if the downtime duration extends from 1 week to 3 weeks, the expected monetary loss might increase in 10 folds.

Keywords: - *Supply Delay, Submersible Pump, Downtime, Economic Loss.*

1. Introduction

In Ethiopia, where there is untapped potential water resource, water-centered economy is getting high attention (Melesse et al., 2014). These days, the frequent drought and failure to access surface water forces to drill deep water wells (Calow et al., 2010). To lift huge amount of water from deep wells, there is no as good as submersible pumps (Gomez & Nortes, 2012; Takacs, 2018). Despite the mechanical damage which is negligible, motor burn is a critical problem of electrical submersible pumps. According to the users and experts in the study area, submersible motor burns due to electric fluctuation and improper utilization. The study in Raya Valley by Tadesse et al. (2015) indicates that sizable water wells cease function because of pump failure. More than the failure loss, the long downtime due to pump supply delay brings much more loss. While irrigation farming is susceptible to lack of water, the water supply downs for long period due to supply delay.

Delay is a function of time and time delay or aftereffect is a real process phenomenon (Richard, 2003). In engineering, aftereffect is researched commonly in construction, control and communication, and supply chain (Richard, 2003; Arditi & Pattanakitchamroon, 2006; Sipahi & Delice, 2008). Delay in supply chain is delivery delay or deviation of lead time from the time defined both by supplier and client (Blackhurst, 2018). Transportation, inventory, information, and decision making are sources of delay (Sipahi & Delice, 2008). The delay times which commonly called the three delays (3D) are lead time delay, transportation delay, and decision making delay (Sipahi & Delice, 2010).

The consequence of delay is economic loss (Sipahi & Delice, 2008) whereas the loss amount may not equal and the delay duration matters. However, in most cases delay time is not constant and considering delay time as a constant in a dynamic system is not realistic. Accordingly, researchers have developed stochastic models which consider the variable delay time (Qiu et al., 2015). Both the discrete and continuous stochastic techniques like that of different probability distribution functions, decision tree with probability, and simulation runs can be used to manage the decision making under uncertainty (Newnan et al., 2004).

This study aims at determining the economic loss of down time in irrigation farming due to pump supply uncertainty and to identify the delay times in the whole supply system. The paper is organized as follows. The next section briefs about the methods and materials like the data collection and analysis tools. In the result and discussion, the 3rd section, the delay probabilities and effect of the delay outcomes are presented. Finally, the conclusion part is presented.

2. Methods and Materials

The study conducted a survey method to investigate the system downtime aftereffect and an analytical method to analyze the probability of delay and the economic loss. Data is collected from key actors and stakeholders such as household farmers, government bodies, technical experts, and suppliers through questionnaires, interviews, group discussions, and referring to recorded historical data. From the survey, pump failure, number of pumps used to date, cost and profit figures of the farm activities, and other related data are collected. The pump related data like pump cost, pump rewinding (maintenance) and supply issue are collected from the randomly selected farmers, technical persons and the suppliers.

The survey is conducted in Northern Ethiopia specifically in Raya Azebo district, a place where it has potential ground water and in the contrast which has critical problem in relation with pump failure and supply delay. It is conducted in 16 randomly selected sample drilled wells (DWs) in which each DW comprises 36 hectares and more than 50 house holder farmers. The cost, production volume, profit and other similar quantitative figures are estimated based on the information provided by those selected farmers. Check list was provided and distributed to 16 farmers in which each farmer comes from the selected 16 DWs.

Downtime delays are analyzed by discrete time delays; 1 week, 2 weeks, 3 weeks and greater than 3 weeks downtime. Then, delay probability in these discrete probability outcomes are estimated based on experts' judgment. The delay's economic loss is also calculated by determining the expected value of cultivation costs, profits and production volumes per hectare and DW. Though it is possible to use other distribution functions, triangular distribution function is used to estimate the expected value of the variables as the date collected fits with it.

3. Results and Discussion

3.1. Delay analysis

From the survey conducted in 16 DWs, a total of 34 failed pumps incident are occurred. The downtime or the delay time, time taken to make functional the DW (until replace the failed pump by new one), of each pump is assessed. Table 1 categorizes the failure incidents in the down time length.

Table 1: Failure incidents category in the downtime length

Downtime length in weeks	1	2	3	4	8	52
No. of failure incidents	7	10	7	7	2	1

Downtime is the delay duration from purchasing new pump until replacing the failed one by new and then makes functional the DW. Here, there are two cases; the actual time taken to process the operation of each activities and the delay time like waiting in queue to process order, waiting for pump supply, waiting for transportation means, and so on.

$$Dt = \text{Ə} + \tau \quad (1)$$

Where Dt is downtime, Ə is the actual time and τ is the delay time. In the other side,

$$Dt = Ot + Tt + Rt \quad (2)$$

Where *Ot* is the order time to process the pump purchasing order, *Tt* is the transportation time and *Rt* is the pump replacement time. In each activity there is a delay (τ). Thus,

$$Dt = Ot\partial + Ot\tau + Tt\partial + Tt\tau + Rt\partial + Rt\tau \quad (3)$$

The order delays may come from; report failures lately, late decision, absence of officials from duty, wait in queue until processing, wait the arrival of orders in case of pump stock out, reject order in case of supply shortage, and information delay. Similarly, transportation delay may come from unavailability of transportation from/to farmland, wait for rig machine and technicians, delay due to road damage, and transportation delay or unavailability to bring pumps from supplier warehouses. Likewise, the delays in association with pump replacement are; absence of technicians from duty, wait to rig truck in case if it is failed, waiting in queue until preceding operations done, and information convey delay.

The throughput time (in this case the downtime), which is the pump supply lead time plus the installation time to make functional the down system, is the summation of Ə and τ. While Ə is constant but τ is variable. In the differential equation for variable time function;

$$f(t) = dt(t) \quad (4)$$

$$f(Dt) = \partial + dt\,(\tau) \quad (5)$$

Where dt(t) is the delay variable time arise due to waiting in queue, transportation delay, information delay, decision making delay, natural and manmade disruption, and so on. Thus, the total downtime function is;

$$f(Dt) = Ot\partial + Tt\partial + Rt\partial + dt\,(Ot\tau + Tt\tau + Rt\tau) \quad (6)$$

$$Ot\tau, Tt\tau \text{ and } Rt\tau \geq 0 \quad (7)$$

OtƏ, TtƏ, and RtƏ are constant. From the survey conducted by interviewing the farmers, the time taken to process the activities in days is estimated as 2, 1 and 1 for OtƏ, TtƏ, and RtƏ respectively. This means, if there was no delay, the total downtime to replace a failed incident is 4 days i.e. less than 1 week. Whereas if we see the data in Table 1 (a data collected by the researcher from the 16 DWs), a DW can down until 52 weeks (1 year) and down more than 1 week in all incidents. This shows there is significant delay in the district.

The delay function can be modeled by probability distribution functions using the survey data in Table 1 as a fundamental input. If the 1 year delay is considered as a special incident, the likelihood of delay time varies from 1 week to 2 months ranges.

Probability distribution function is used as it is more realistic than a deterministic approach (Sun, 2017). Although continuous probability can enable to get high range solutions, taking few but high likelihood discrete probability outcomes is simple to compute the expected value. In engineering applications, which don't necessarily need continuous out comes, such model is common (Newnan et al., 2004). Table 2 shows the delay outcomes and its occurrence probability. The probability of occurrence is estimated after asking the farmers in the 16 DWs. The 4th outcome, greater than 3, is designed by assuming that all vegetables on the farm will be destroyed if they couldn't get water for more than 3 weeks.

Table 2: Delay outcomes and the probability of occurrence

Delay outcomes in wks	1	2	3	>3
Probability of occurrence	0.2	0.3	0.2	0.3

3.2. The Economic Consequence of Delay

Since plants are vulnerable to water deficiency, the loss amount increases radically while the downtime increases. The expected losses are: productivity minimization loss (P*l*), destroyed loss (*Dl*), and opportunity loss (*Ol*). P*l* is the yield minimization due to not getting enough water. *Dl* is complete destroy of plants in farmland due to lack of water and it is equivalent with the total cost invested to cultivate the plants. Likewise, *Ol* is the amount of profit gone if the plants were harvested. Thus, downtime cost (*Dt cost*) is;

$$Dt\ cost = Pl + Dl + Ol \quad (8)$$

To determine the lost amount precisely, detail estimation of each variable is required. In this study, however, it is estimated based on the experienced farmer's expertize judgment (being expert here is the year of experience in the farming activities). As shown in Table 3, the lost percentile increases dramatically while downtime increases by few days. The percentile indicates the amount of loss from the total productivity.

Table 3: Basic assumptions of the lost percentile for the delay outcomes

Lost types and loss amount	Downtime duration (weeks)			
	1	2	3	>3
Productivity minimization in %	10	25	50	
Destroy/loss in %				100
Opportunity lost in %				100

The next task is to drill down the irrigation business costs and profits to calculate the total lost. The farmers cultivate various vegetables and crop types three times per year. The basic vegetables and crops that have been cultivated in the area are; onion, tomato, watermelon, pepper, maize, and teff. From now on ward P_1, P_2, P_3, P_4, P_5 and P_6 represents to onion, tomato, watermelon, pepper, maize and teff, respectively. The detail of the costs that would incur to cultivate the vegetables in irrigation per hectare in one round is summarized as in Table 4.

Table 4. Cost of different products in one hectare

Cost types in per hectare for one term	Cost of each product (Ethiopian Birr (ETB))					
	P1	P2	P3	P4	P5	P6
Land rent	7500	7500	7500	7500	7500	7500
Water consumption fee	1500	1500	1500	1500	1500	1500
Land preparation	5000	5000	5000	5000	5000	5000
Nursery/seed cost	10000	4000	1000	1000	500	500
Labor cost for transplanting the nursery	4500	2000	0	2000	0	0
Fertilizer	6000	6000	1500	3000	6000	6000
Pesticide	3000	5000	2000	1000	800	400
Labor cost of watering and pesticide works	2500	2500	2000	1500	1500	1500
Labor cost for Weeding and related works	8000	5000	3000	2000	2000	2000
Total cost	48000	38500	23500	24500	24800	24400
Weight (the ratio of each type)	0.4	0.3	0.1	0.05	0.1	0.05

To get the most likely cost based on the probability functions, triangular distribution is used. The weighted average indicates the density of the distribution. Since the weight of P_3-P_6 is totaled to 0.3, the mean value of these three is taken as a one value of the triangle.

$$Mean\ value = \frac{23500 + 24500 + 24400}{4} = 24300$$

$$TRIA(24300{,}48000{,}38500) = TRIA\ (a, b, c)$$

The following is a probability density of the triangular distribution function (Allen, 2006).

$$f(x) = 0 \qquad if\ x \le a\ or\ x \ge b \tag{9}$$

$$f(x) = \frac{2(x-a)}{(b-a)(c-a)} \qquad if\ a < x \le c \tag{10}$$

$$f(x) = \frac{2(b-x)}{(b-a)(b-c)} \qquad if\ c < x < b \tag{11}$$

A mean of random variable of the probability density function is given by

$$\text{Mean value } (\mu) = \int_{-\infty}^{\infty} xf(x)dx \tag{12}$$

$$\mu = 0 + \int_a^c xf(x)dx + \int_c^b xf(x)dx \tag{13}$$

$$\mu = 0 + \int_{24300}^{38500} xf(x)dx + \int_{38500}^{48000} xf(x)dx$$

$$\mu = 0 + \int_{24300}^{38500} x\frac{2(x-24300)}{(48000-24300)(38500-24300)}dx + \int_{38500}^{48000} x\frac{2(48000-x)}{(48000-24300)(48000-38500)}dx = 36{,}915.4$$

Expected cost for one hectare in one round is, therefore, expected to ETB 36,915.4.

To calculate the profit, sales volume should get first. Since the quantity getting from one hectare varies from time to time as well the sales price varies also, 5 different values are taken by asking the users. In Table 5, Q stands for quantity and Pr for price.

Table 5. Sales volume of the different outputs based on the data in 2017/18 calendar

		Types of vegetables/crops					
		P1	P2	P3	P4	P5	P6
Quantity in quintal in hectare (hr)	Q1	200	200	160	100	60	40
	Q2	140	160	120	80	40	25
	Q3	80	100	80	60	35	15
	Q4	60	60	40	40	25	10
	Ave.	120	130	100	75	40	22.5
Price/kilo (ETB)	Pr1	14	12	8	20	10	18
	Pr2	10	10	7	15	9	17
	Pr3	6	4	4	10	8	14
	Pr4	2	2	3	8	7	13
	Ave.	8	7	5.5	13.25	8.5	15.5
Sales volume (ETB)		96000	91000	55000	99375	34000	34875

Profit (p) is the subtraction of the cost (c) from the sales volume (s).

$$p = s - c \tag{14}$$

Hence, profit can be calculated easily from table 4 and 5 and it is compiled as in table 6.

Table 6. Profit estimation

One hr's	Types of vegetables/crops					
	P1	P2	P3	P4	P5	P6
Sales volume (ETB)	96000	91000	55000	99375	34000	50375
Cost (ETB)	48000	38500	23500	24500	24800	24400
Profit (ETB)	48000	52500	31500	74875	9200	25975

The mean is estimated based on the triangular probability distribution.

$$\text{TRIA}\ (9200, 48000, 74875) = \text{TRIA}\ (a, b, c)$$

The following is a probability density of the triangular distribution. A mean of random variable of the probability density function is given by;

$$\mu = 0 + \int_{15200}^{54000} x f(x) dx + \int_{54000}^{58500} x f(x) dx$$

$$\mu$$
$$= 0 + \int_{9200}^{48000} x \frac{2(x - 9200)}{(74875 - 9200)(48000 - 9200)} dx$$
$$+ \int_{48000}^{74875} x \frac{2(74875 - x)}{(74875 - 9200)(74875 - 48000)} dx$$
$$= 44{,}000$$

The expected net profit from one hr in one round is ETB 44,000.

It is assumed that the average hectares in one DW are 36. The number of hectares that require water (on hectares) or doesn't require (off hectares) should be estimated to know the amount under risk. Those which don't need water are not only that of uncovered by crops but also it includes those which cover by plantation but no more need water. According to the data collected from the site, the ratio of on-hectares and off-hectares is 65% to 35% or it is around 22 by 14 hectares respectively. Expected sales volume (*Es*) per hectare is calculated from the expected cost and profit.

$$\mu s = \mu c + \mu p \tag{15}$$

$$\mu s = 36{,}915 + 44{,}000 = \text{ETB } 80{,}915/\text{hr}$$

This means in Raya Azebo, the case study site, from one hectare in one round revenue of ETB 80,915 per hectare is expected. In the other side, it is said that;

$$\text{Dt cost} = \text{Pl} + \text{Dl} + \text{Ol} \qquad (16)$$

Risk of 1 week down time is the Pl which is 10% of the μs

$$\text{Dt cost 1 week} = 0.1\ \mu s$$

$$\begin{aligned}\text{Dt cost 1 week} &= 0.1 * 80{,}915 \\ &= 8{,}091.5/\text{hectar or } 8{,}091.5 * 22 \\ &= 178{,}013/\text{DW}\end{aligned}$$

This means if one pump is down for 1 week ETB 178,013 will be lost in the DW areal coverage since production is lost as a result of the downtime.

$$\begin{aligned}\text{Dt cost 2 wks} &= 0.25 * 80{,}915 \\ &= 20{,}228.75/\text{hr or } 20{,}228.75 * 22 \\ &= 445{,}032.5/\text{DW}\end{aligned}$$

$$\begin{aligned}\text{Dt cost 3 wks} &= 0.5 * 80{,}915 \\ &= 40{,}457.5/\text{hr or } 40{,}457.5 * 22 \\ &= 890{,}065/\text{DW}\end{aligned}$$

Dt cost for more than 3 weeks is the summation of the Dl and Ol. While Dl is the expected cost, opportunity cost is the expected profit. This means that Dt cost for greater than 3 weeks is equivalent to the total expected sales volume.

$$\text{Dt cost} > 3\ wks = Dl + Ol = \mu s$$

$$\begin{aligned}\text{Dt cost} > 3\ week &= (80{,}915)/hectare \\ &= 80{,}915 * 22 = 1{,}780{,}130/\ DW\end{aligned}$$

This implies if water supply system is down for more than 3 weeks, the farmers in one DW can lose a gross of ETB 1,780,130. All in all, as down time interval increases the severity of the risk increases radically. The downtime lost for each down time interval is exhibited in Figure 1.

3.2. Total Delay Loss

The last analysis is to integrate Table 2 and Figure 1. The probability of delay is estimated as depicted in Table 2 and in Figure 1 the expected loss in each outcome is estimated. Based on this, the total expected delay loss cost (μτc) is the summation of the 4 outcomes' expected cost (μc) multiplied by the outcomes' probability of occurrence. This is modeled as below.

$$\begin{aligned}\mu\tau c = {} & \mu c \text{ of 1 wk} * p(\tau \text{ 1 wk}) + \mu c \text{ of 2 wks} * p(\tau \text{ 2 wks}) \\ & + \mu c \text{ of 3 wks} * p(\tau \text{ 3 wks}) + \mu c \text{ of} \\ & > 3\ wks * p(\tau > 3\ wks)\end{aligned}$$

$$\begin{aligned}\mu\tau c = {} & 8091.5 * 0.2 + 20228.75 * 0.3 + 40457.5 * 0.2 \\ & + 80195 * 0.3 = \text{ETB } 39{,}836.925\end{aligned}$$

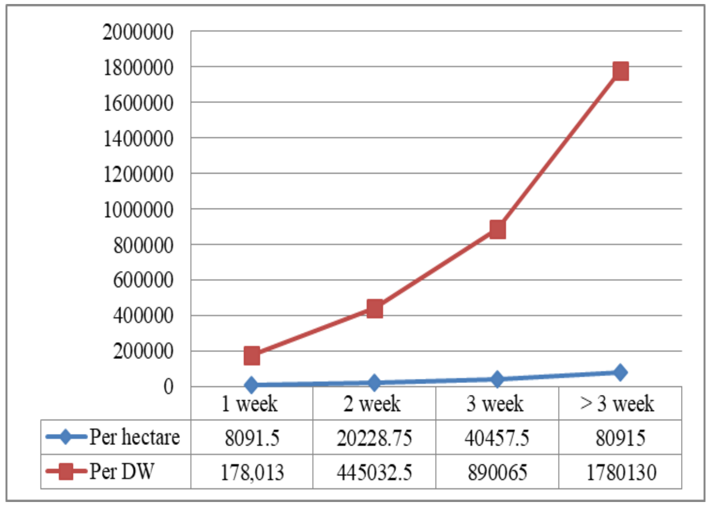

Figure 1. Downtime costs of various durations

The total expected delay loss cost per hectare in the case study is ETB 39,836.925. The total expected loss cost per DW is,

$$\text{Total loss/DW} = 39{,}836.925 * 22 = \text{ETB } 876{,}412.35$$

Currently, the administrators have reported that per year 5 pumps are failed. If this number is taken to estimate the total loss in the district as a result of delay;

$$\begin{aligned}\text{Yearly loss} &= \frac{\text{loss}}{\text{DW}} * \text{number of DWs} = 876{,}412.35 * 5 \\ &= 4.4 \text{ million}\end{aligned}$$

Thus it is estimated that, in Raya Azebo district, ETB 4.4 million/year is lost due to supply delay. If this number is used to estimate the loss in nationwide, it could be very huge. If it is expected also that similar delay scenarios are happened in other developing countries, the model can use to estimate similar delay losses.

4. Conclusion

Determining expected delay time using deterministic approach is dispensable method for variables which are not certainly known. To overcome such challenges, probabilistic (stochastic) approach is a sound solution to make decision under uncertainty. Discrete time probability outcomes are taken based on experts' judgment to represent the possible expected delays. Although continuous probability out comes can help to widen the solution range, taking few but high likelihood discrete probability outcomes based on experts' judgment is representative and simple to compute the expected value and this is especially common in engineering applications which didn't necessarily need continuous out comes. Likewise, economic loss costs can be estimated in a better but manageable way using triangular distribution functions.

In this study, the water supply system downtime of the irrigation farm in Raya Azebo district due to pump supply delay is investigated and it is found that the pump supply delay is lengthy and uncertain. The delay probability outcomes and the expected loss outcomes are integrated to compute the economic loss. Accordingly, aftereffect of submersible pump supply in groundwater irrigation farming is measured in economic loss. The economic loss in one irrigation district, in Raya Azebo, Northern Ethiopia, is estimated to be ETB 4 million annually. When taking this figure to compute the aftereffect loss in nationwide it could be a terrible number. This shows how delay disruption affects the business in developing countries. This research can serve as an input to the policy makers, researchers, practitioners, and consultancies who engage in irrigation farming in developing countries.

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