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HYDRODYNAMIC MODELLING OF A SEA-CROSSING BRIDGE IN THE MALDIVES

Hassan Shiraz¹
Mohamad Hidayat Jamal²

¹Maldives National University, Universiti Tekonologi Malaysia (Email: hassan.shiraz@mnu.edu.mv)

²Maldives National University, Universiti Tekonologi Malaysia (Email: mhidayat@utm.my)

Abstract: ‘Gaadhoo Koa Channel’ is an atoll pass located in the southern tip of Malé Atoll, Maldives, separating the capital city, Malé, and the main international airport, Hulhulé island. The Gaadhoo Koa channel is known for its strong tidal flow and strong swell waves and is located in a strategic area which includes the main shipping lane for Malé port and also marine traffic lanes connecting both Malé and Hulhulé with nearby islands. Recently, a sea-crossing bridge has been constructed across the channel connecting these two islands. This involved in the construction of 21 bridge piers across the channel which raised concerns on the potential negative impacts on the flow regime in the vicinity of the bridge. This paper presents a numerical modelling study to investigate the hydrodynamic impact of the bridge piers in the Gaadhoo Koa channel using Delft3D-FLOW modelling software. The model results were calibrated against water level data from Hulhulé station and finally model simulations were run to assess the hydrodynamic impact of the bridge piers. The results indicated that the flows in the close vicinity of the bridge were reduced with the introduction of bridge piers. Also, the magnitude of flow velocity reduced around bridge piers and increased in between bridge piers. Furthermore, the overall velocity distribution in the northern region from the bridge showed a decreasing pattern while the southern region showed an increasing pattern: peak velocity in the northern region decreased by 7.3 % at about 500 m from bridge whereas peak velocity in the southern region raised by 33% at also about 500 m from bridge. Based on these findings, it can be considered that the introduction of bridge piers can have a considerable impact on the hydrodynamic conditions of Gaadhoo Koa atoll pass.

Keywords: Gaadhoo Koa atoll pass, sea-crossing bridge, bridge piers, numerical modelling, Delft3D-FLOW

Introduction

The Gaadhoo Koa atoll pass separating Hulhulé and Malé Island in the Maldives is the main shipping lane for Malé port. The channel experiences strong tidal flow and receives strong swells from the southeast (SE) direction. In particular, the wave conditions on the SE reef corner of Malé, which is a prominent surf spot, and on the southern tip of Hulhulé Island are particularly strong. A water crossing bridge connecting these two islands has been constructed and opened in August 2018, covering an overwater length of 1.39 km (CSET & CDE., 2015). Some studies (Guo et al., 2016) has shown that the hydrodynamics of overwater bridges has caused notable changes in the flow fields over a domain that can extend as far as one km from bridge locations. These changes were most prominent in the vicinity of bridge piers. However, there is limited literature on the effect of overwater bridges in atoll environments. Hence, it is essential to predict potential



hydrodynamic changes in order to assess the physical impact of the overwater bridge on the flow field across Gaadhoo Koa channel. Therefore, the objectives of this work were to develop a numerical model to simulate the hydrodynamics of Gaadhoo Koa region and to assess the hydrodynamic impact of sea-crossing bridge across the channel.

In this study, a two-dimensional hydrodynamic model was setup for the Gaadhoo Koa region which comprises gentle reef slopes on either side of a deep oceanic channel. Only the flow module of the model programme, which focuses on unsteady flows due to tidal and meteorological forces was considered in this study. Model was calibrated using the observed water level data from Hulhulé station. After that, simulations were run with the effect of bridge piers included and the impact on hydrodynamic conditions in relation to current and tidal flows across the channel were evaluated.

Literature review

Hydrodynamics of the Site

The Gaadhoo Koa atoll pass between Malé and Hulhulé Island has a channel width of 1400 m. The channel area experiences strong tidal currents and receive strong swells from the southeast direction accompanied by strong winds.

Based on the gauge data collected from sea level monitoring station in Hulhulé, it has been reported that the tides along the east coast of Malé is in the category, ‘Mixed Semidiurnal’ with two high tides and two low tides per day of varying amplitudes (Indika et al., 2017). The spring tidal range and the neap tidal range were 0.652m and 0.176 respectively and the monthly mean sea level ranged between 8-15 cm. The maximum mean sea level change was recorded between December and January while the minimum level was recorded during September to October. Besides the monthly variability of tidal water levels, past records show a significant inter annual variability in the sea level. The long-term annual sea level data for the past 20 years indicates a rise of 3.753 mm per year in Malé (MEE, 2016).

The waves observed along the Maldives islands can be classified into two major types. The first type is the monsoon driven wind waves with a period of 3 to 8 seconds and the second type is ocean swells generated by distant storms with a period ranging from 8 to 20 seconds (Kench et al., 2006). These waves are typically strongest during April – July in the southwest (SW) monsoon period. The satellite altimetry wave climate data for the region indicates the dominant swell waves approach from the southwest to southerly directions (Young, 1999) with a peak significant wave height of 1.8 m in June. It has also been reported that the region has observed swells generated north of the equator with heights of 2 to 3 m (MEC, 2004). The bridge site is located on the SE rim of the atoll rim and is fairly protected from the northeast (NE) swells while being well exposed to swell waves approaching from SE direction. Hence it is expected that the site is more susceptible towards wave action during the SW monsoon and transition period.

Currents that affect the reef pass can be caused by the interaction of oceanic currents, tidal currents, local wind-induced currents and wave-induced currents. Some studies indicate that ocean currents and tidal currents to be the dominant forms in the region (CUSP, 2011). Ocean surface currents are driven by the wind action (Trujillo & Thurman, 2016) and the current regime in the Indian Ocean is greatly influenced by the monsoon climate. In the Maldives archipelago the currents flow westward during the NE monsoon period, and they flow eastward during the SW



monsoon period (MEC, 2004). Tidal currents are strongest during spring tide periods when the tide range is greatest (CUSP, 2011).

Hydrodynamic Impacts of Sea-Crossing Bridges.

The literature on the numerical modelling studies on hydrodynamical impacts associated with water crossing bridges is limited. Guo et al. (2016) simulated the changes in the tidal flow field in Quanzhou Bay due to a newly constructed sea crossing bridge. The results showed that slow flow areas were present in front of bridge piers due to the influence of rising and falling tides. Furthermore, slow flow areas were also formed at the back of the piers after the rising and falling tides passed the piers. The upstream and downstream flow along the bridge was found to be influenced over a distance approximately 1 km away. It was also found that sediment deposits around the main bridge pier increased while the sediment suspension decreased in between piers. These changes could potentially impact the navigation in the Quanzhou Bay. Similarly, Pun and Law (2015) studied the influence of the bridge piers of six bridges on the tidal exchange in Rambler Channel located in Hong Kong. It was observed that the combined effect of all the bridges significantly decreased the tidal flow rate, restricting the tidal movement in the channel. Additionally, it was noted that the bridge piers modified the tidal flow path at the surface water layer, triggering a negative impact to flushing out contaminants from the channel. Li et al. (2014) also simulated the hydrodynamic processes due to a water-crossing bridge in Jiaozhou Bay, China, and found that the bridge significantly affected the hydrodynamics at the bay entrance, waterways and north side of the bridge.

Most of the studies show that the influence zone of hydrodynamic impact due to bridges were mainly limited to the regions in the close vicinity of the bridge. For instance, the hydrodynamic modelling of the Hangzhou Bay Bridge (Pang et al., 2008) indicated that the impact of bridge piers on the hydrodynamic setting was limited to a small region surrounding the bridge. This suggests that the relative size of the bridge span and surrounding water area could affect the degree of the impact. On the other hand, the impact of flow changes due to piers will be much greater if the bridge lies in a channel subjected to strong current and complex terrain (Zhao et al., 2015).

Methodology

Figure 1 displays a flow chart of the methodologies that were used in this study. The flowchart comprises four main phases: (1) model selection (2) model inputs (3) model setup and (4) model simulation and analysis. Each phase is detailed in the following sections.

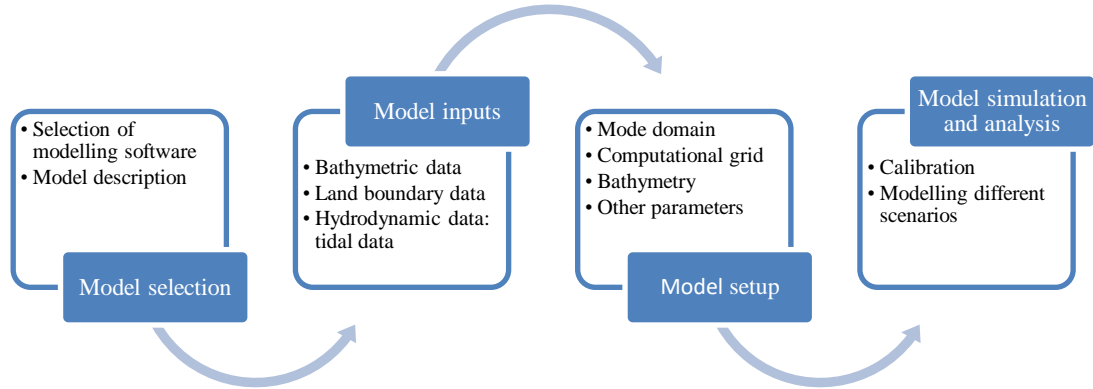


Figure 1: Flowchart of the study.

Model selection

There are a broad range of numerical modelling software available for hydrodynamic modelling including Telemac-2D model, MIKE21 model and Delft3D. A background study of these three software was conducted to determine the best modelling option. The main constraints considered in software selection were their costs (if any) and availability of documentation. MIKE21 was not possible as it was an expensive software to acquire. On the other hand, Telemac-2D and Delft3D are freely available as open source software. Eventually it was decided to use Delft3D because there are more documentations and a more active user community when compared to Telemac2D.

The Delft3D is a multi-disciplinary software suite developed to model unsteady water flow, temperature, salinity and cohesive/non-cohesive sediment transport in shallows seas, estuarine and coastal areas, rivers and lakes. The Delft3D-FLOW module was used to model water motion due to tidal and meteorological forcing by solving the unsteady shallow-water equations that consist of the continuity equation, the horizontal momentum equations, and the transport equation under the shallow water and Boussinesq assumptions by an implicit finite difference method on an unstructured grid. The continuity equation and momentum equations can be described as follows (Deltares, 2018):

$$\frac{\partial h}{\partial t} + \frac{\partial Uh}{\partial x} + \frac{\partial Vh}{\partial y} = \int_0^h (q_{in} - q_{out}) dz + P - E = Q \quad (1)$$

with U and V , the depth averaged velocities. Q represent the contributions per unit area due to the discharge or withdrawal of water, precipitation and evaporation with q_{in} and q_{out} the local sources and sinks of water per unit of volume respectively, P the non-local source term of precipitation and E non-local sink term due to evaporation. The momentum equations in x- and y-direction are given by:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_0} \frac{\partial P}{\partial x} + F_x + \frac{\partial}{\partial z} \left(\nu_v \frac{\partial u}{\partial z} \right) + M_x \quad (2)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} - fu = -\frac{1}{\rho_0} \frac{\partial P}{\partial y} + F_y + \frac{\partial}{\partial z} \left(\nu_v \frac{\partial v}{\partial z} \right) + M_y \quad (3)$$

where ν_v is the vertical eddy viscosity coefficient. Density variations are neglected, except in the baroclinic pressure terms, $\partial P/\partial x$ and $\partial P/\partial y$ represent the pressure gradients. The forces F_x and F_y in the momentum equations represent the unbalance of horizontal Reynolds stresses. M_x and M_y represent the contributions due to external sources or sinks of momentum.

Model Inputs

Bathymetric data was obtained from ‘The General Bathymetric Chart of the Oceans’ (British Oceanographic Data Centre, 2009) and tide data measured from tide gauge located in Malé International Airport was obtained from University of Hawaii Sea Level database (Caldwell et al., 2015).

Model Domain

The model domain (Figure 2) was chosen in such a way that it represented the bridge site and all the islands connected by the bridge. The domain extends 7 km horizontally and 10 km vertically encompassing the two islands, Malé and Hulhumalé, connected by a water-crossing bridge. This was used as a basis to create the land boundary input file for Delft3D-FLOW GUI.

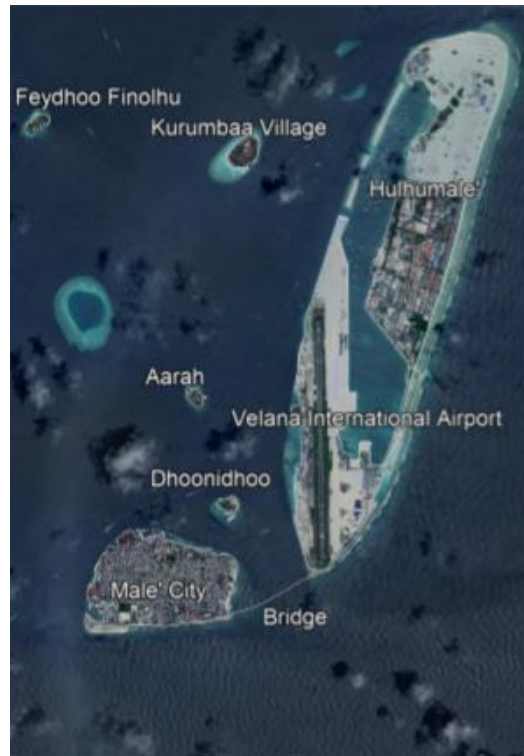


Figure 2: Model area showing bridge location, atoll pass and the surrounding islands.

Computational Grid

For this work, a rectilinear computational grid was generated using the Delft3D RGFGRID tool. In order to save computation time, the resolution of grid was refined in such a way that the areas lying outside the hypothesised influence zone due to the bridge had a lower resolution compared to the vicinity of the bridge. The resulting computational grid had 134 cells in the M (horizontal)-direction and 182 cells in the N (vertical) -direction with a total of 20,483 grid cells. For a good quality grid, the orthogonality should be less than 0.02, aspect ratio must be in the range [1 to 2] and M/N smoothness should be less than 1.2 with a maximum value of 1.4 in the areas of interest (Deltares, 2018). Using the tools in RGFGRID tool, it was found that all of these conditions were satisfied. The final computational grid is presented in Figure 3.

Bathymetry

The bathymetric data was automatically generated in terms of cartesian coordinates using the Delft3D Dashboard too which is based on 'The General Bathymetric Chart of the Oceans' (British Oceanographic Data Centre, 2009). Although the resolution of this data was low, this was the only data available at the time of model setup. Hence, some post processing of the generated data was carried out using the QUICKIN tool which allowed to copy depths into samples and interpolate the resulting samples by triangular interpolation to obtain depth at each grid cell of the generated grid. The final bathymetry for the model domain is presented in Figure 4.

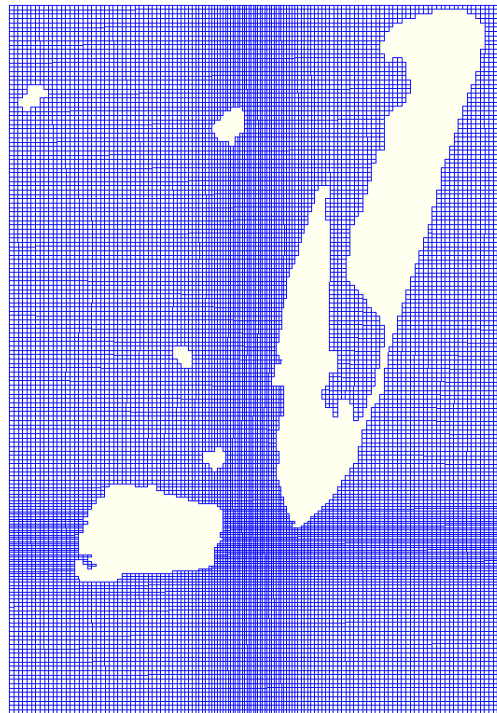


Figure 3: Generated computational grid in RGFGRID window.

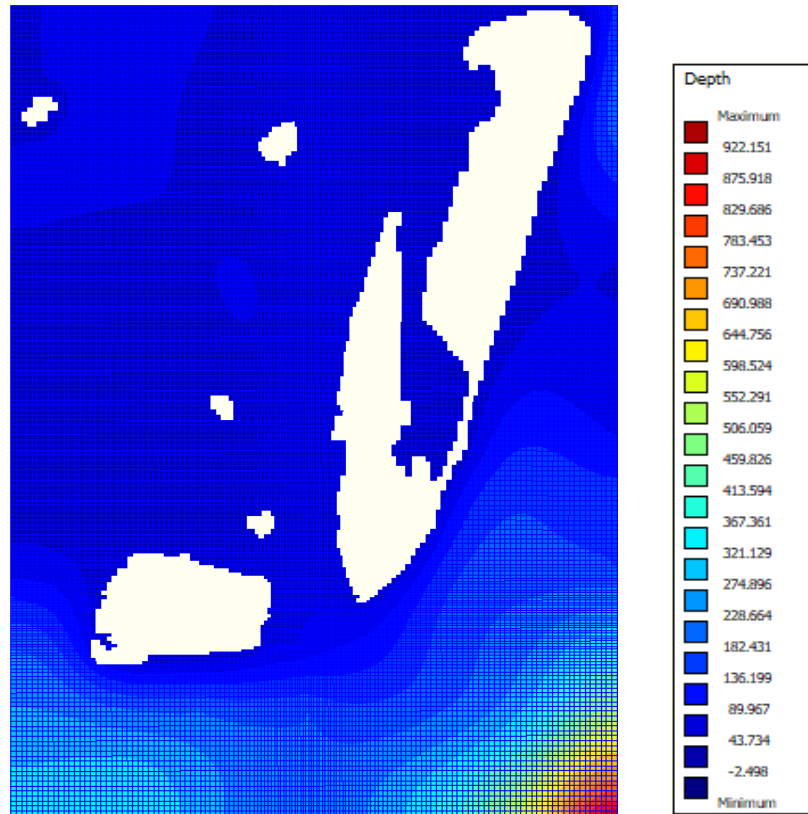


Figure 4: Top view of the bathymetry layout in QUICKIN window.

Boundary conditions

Boundary conditions in the form of astronomical constituents at all the four open boundaries surrounding the model domain were generated from the Delft Dashboard tool using tidal constituents from the Oregon State University global inverse tide model containing 13 tidal constituents (Egbert & Erofeeva, 2002).

Time-step

In order to maintain the numerical stability and accuracy of the model in Delft3D-Flow, the values of courant number were checked. The courant number, C , is given by

$$C = 2\Delta t \sqrt{gH} \sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}} \quad (4)$$

where Δt is the time step, g is the acceleration of gravity, H is the total water depth and Δx and Δy are the smallest grid spaces in M and N-direction of the mode domain. Generally, the courant number should not exceed a value of ten (Deltares, 2018). The Courant number of the model domain was evaluated using the QUICKIN and a step time of 1.5 seconds was adopted as this was the minimum time for which courant number was less than ten.



Model Calibration

During the calibration stage, the main focus was to calibrate the water levels and also the current velocity. However, due to unavailability of observed current data, only water level calibration was considered. Water level observations over a period of thirty days from Hulhulé tide station was used for calibration against modelled results for both spring and neap tide conditions. The model performance was then assessed based on minimum level of performance indicators in coastal hydrodynamic models defined in terms of Root Mean Square Error (*RMSE*), Bias, Correlation (*R*) and Scatter Index (*SI*) (Williams & Esteves, 2017). These performance indicators are described in Table 1 where N is the number of observations, O_i is the i -th observation, S_i is the i -th model simulated value. Results of the calibration analysis will be discussed in section 4.

Table 1: Mode performance indicators (Williams & Esteves, 2017).

Performance indicator	Description	Formula
Root Mean Square Error (<i>RMSE</i>)	measure of the differences between measured (S) and modelled data	$RMSE = \sqrt{\frac{\sum_{i=1}^{N_i} (S_i - O_i)^2}{N_i}} \quad (5)$
Bias	expresses the difference between an estimator's expectation and the true value	$Bias = \sum_{i=1}^N \frac{1}{N_i} (S_i - O_i)^2 \quad (6)$
Correlation (R)	a measure of agreement between measured/observed data	<i>Obtained from excel data analysis package</i>
Scatter Index (SI)	the <i>RMSE</i> normalised with the mean value and it provides an indication of the model performance	$SI = \frac{\sqrt{\frac{1}{N_i} \sum_{i=1}^N (S_i - O_i)^2}}{\frac{1}{N_i} \sum_{i=1}^N O_i} \times 100 \quad (7)$

Model Simulation for Various Scenarios

After calibration, model simulations were run to study the impact of the bridge piers on the hydrodynamics of Gaadhoo Koa atoll pass. In Delft3D, a bridge pier is treated as a porous plate which is defined as a partly transparent structure that have a thickness much smaller than the grid size in the direction perpendicular to the porous plate, that extends into the flow along one of the grid directions while covering some or all layers in the vertical (Deltares, 2018). Partial transparency of the porous plate results in the exchange of mass and momentum across it, generating energy losses. To account for this energy loss, a quadratic energy term is added to the momentum equation as given below.

$$M_\xi = -\frac{C_{loss-u}}{\Delta x} u \sqrt{u^2 + v^2} \quad (8)$$

$$M_\eta = -\frac{C_{loss-v}}{\Delta y} v \sqrt{u^2 + v^2} \quad (9)$$



with c_{loss} the energy loss coefficient or quadratic friction term given by:

$$C_{loss-u} = \frac{NC_{drag}d_{pile}}{2\Delta y} \left(\frac{A_{tot}}{A_{eff}} \right)^2 \quad (10)$$

with:

A_{tot} total cross-sectional area

A_{eff} effective wet cross-sectional area (A_{tot} minus the area blocked by piles: $A_{eff} = A_{tot} - \zeta Nd_{pile}$).

C_{drag} the drag coefficient of a pier (pile) (1.0 for a smooth cylindrical pile).

d_{pile} the diameter of a pile.

N the number of piles in the grid cell.

Porous plates are defined inside the grid enclosure and can only be defined at multiples of 45-degree angles with the grid directions. To include porous plates in this work a porous plate file (.ppl) was created which specified the direction of the porous plates normal to the flow, the start and the end node of the grid where the porous plates were located and the vertical layers that the porous plates were extended and finally, the quadratic friction term, C_{loss} . The bridge under this study contains a total of 26 piers and number of piles in these piers and their corresponding diameters obtained from CSET & CDE. (2015) and the computed friction parameters are listed in Table 2.

Table 2: Bridge pier number, diameters and friction loss parameters.

Pier number(s)	Number of piles, N and diameter, d (m)	Friction factor C_{loss-u}	Friction factor C_{loss-v}
1 to 10	$N = 4, d = 1.5$	0.298	0.298
11 to 18	$N = 6, d = 1.5$	0.576	0.446
19 to 21	$N = 12, d = 2.5 \text{ to } 2.8$	1.185	0.928
22 and 23	$N = 8, d = 2.5 \text{ to } 2.8$	1.185	0.498
24, 25, 26	$N = 4, d = 1.5$	0.119	0.119

Results and Discussion

Initial model

The initial model was carried out without the effects of the bridge piers and the results were used for calibration. Figure 5 illustrates the velocity vectors representing tidal flows for both flood and ebb tides at the entrance of Gaadhoo Koa atoll pass. It can be seen that during flood tide the tidal flow is heading towards south and as it approaches the entrance of the channel it shifts south-east eventually flowing easterly as the water moves away from the channel entrance. Conversely, during ebb tide, majority of the tidal flow is oriented north at the entrance point of the channel and as the flow advance further into the atoll, the direction shifts north-west. However, a closer look at the central area in the Figure 5 (right) reveals that part of the tidal flow initially headed north reverses direction at the centre of the region between the two islands and flows back in a south-easterly direction. It can also be observed that the highest flow occurs at the centre of the channel during flood tide with a magnitude ranging from 6 to 10 cm/s. On the other hand, the flow speeds during ebb tide have noticeably lower values ranging from 1 to 4 cm/s. These values indicate that the overall speed of current flow is greater during flood tide when the water is flowing out of the atoll pass towards deeper ocean.

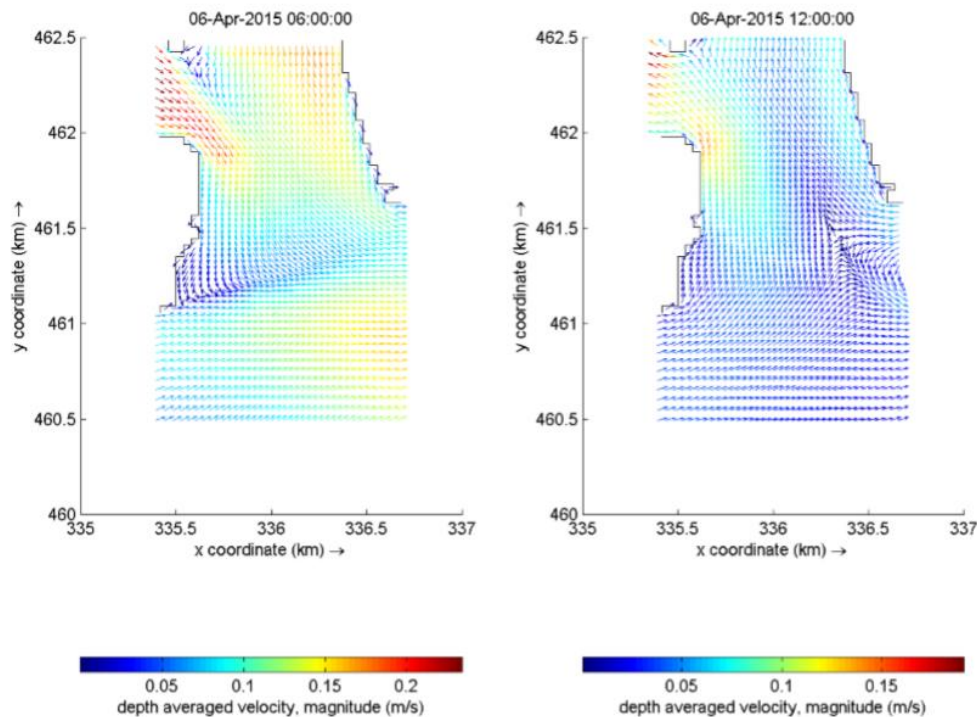


Figure 5: Flow vectors during flood tide (left) and ebb tide (right).

Calibration and validation of water level

In order improve the model performance, it was calibrated against the observed water level data from the Hulhulé tide station. Observed data was obtained from 1st April 2015 to 30th April 2015 covering two spring and two neap tide cycles. The calibration parameters considered during calibration were the Manning’s friction coefficient, n , which was initially assumed to be 0.02 in both directions and eddy viscosity which was assumed to be $1 \text{ m}^2/\text{s}$. However, model results for various values of friction coefficient and eddy viscosity revealed no significant improvements in the minor discrepancies between modelled and observed water levels and in some cases these discrepancies increased. Therefore, it was assumed that the initially assumed values of friction coefficient and eddy viscosity were acceptable in modelling the water level.

The calibrated and observed water levels during neap tide and spring tide cycles are presented in Figure 6 and Figure 7 respectively. It is evident from the figures that the calibrated water levels are in good agreement with the observed water levels. Additionally, it can be observed that over a 24-hour period two low tides and two high tides occurs in both the curves which is a characteristic feature of semi-diurnal tidal patterns. During neap tide water level varied roughly between 0.17 m to -0.2 m resulting in a total tidal range of 0.37 m. On the other hand, during spring tide, water level varied roughly between 0.41 m to -0.44 m resulting in a total tidal range of 0.85 m.

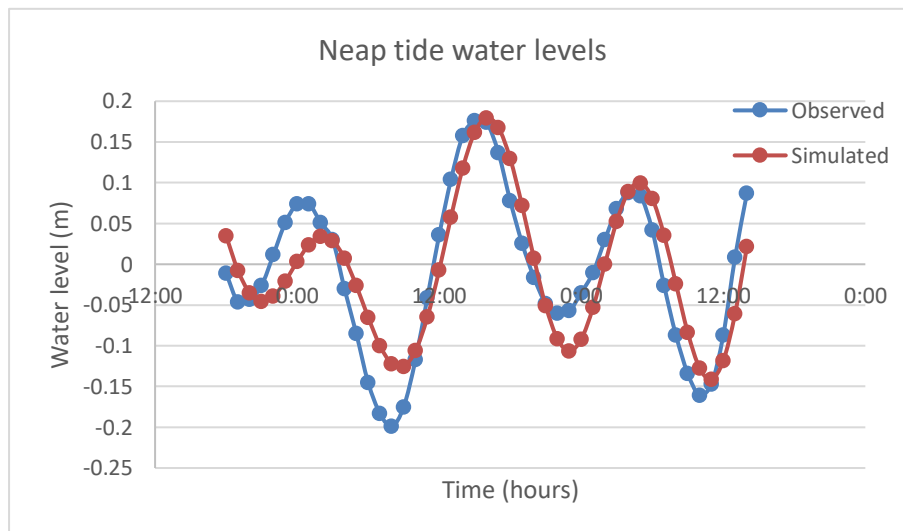


Figure 6: Neap tide water levels.

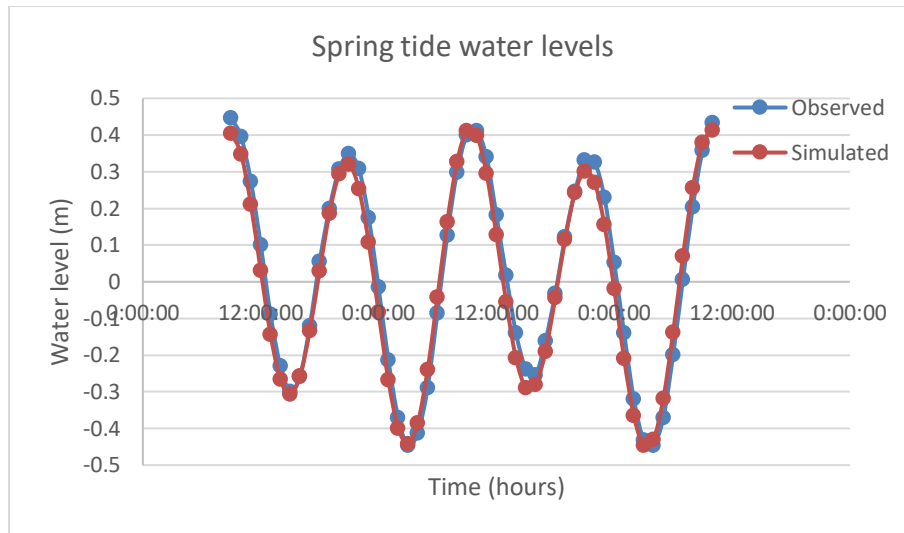


Figure 7: Spring tide water levels.

The standard levels for minimum performance suggested by Williams and Esteves (2017) and the computed values for the calibrated model are listed in Table 3. Based on these results, the maximum mean difference of water level is 0.044 m (4.4%) and 0.045 m (4.5%) during neap tide. Both of these values are less than the standard values of 10% and 15%. Additionally, the calculated bias (0.049) and correlation coefficient (0.985) are also within the acceptable limits.

Furthermore, the scatter index calculated was 1.86% which is less than the standard maximum level of 10%. Therefore, it can be concluded that the calibrated model accurately simulates both spring and neap tidal levels.

Table 3: Results of statistical analysis for model performance.

Performance indicator	Standards for minimum level of performance	Calculated values for calibrated water level
RMSE spring tide	10% of the measured level	4.4
RMSE neap tide	15% of the measured level	4.5
Bias	<0.10	0.049
R	>0.95	0.985
SI	<10%	1.86 %

Simulation of the hydrodynamic impact due to the bridge

Figure 8 shows the magnitude of the residual velocity during flood tide and ebb tide due to the effect of bridge piers. During flood tide, it can be seen clearly that the magnitude of upstream velocity has increased as the flow approaches the bridge and the velocities have decreased in downstream region when the effect of bridge pier is included. However, at the central region of the bridge the downstream velocity increases locally up to a distance of about 200 meters and as the flow proceeds further, it can be observed that the velocity reduces. Further inspections of the impacted area reveal that the influence area for downstream changes in the velocity magnitude extends up to 400 meters laterally from the bridge centre and the majority of these changes are

observed on the eastern region of the bridge. The increased upstream and downstream velocities during flood tides in the central region corresponding to the navigational area is similar to the results by Xiao Feng et al (2015) showing that at the main navigational area corresponding to the greatest water depth, the upstream velocity increased locally while the downstream velocity decreased. However, the scale of impacted region in this case differs considerably from the results of this research. According to Xiao Feng et al (2015), the impacted upstream zone was much smaller compared to the downstream zone while in our case it is the other way around.

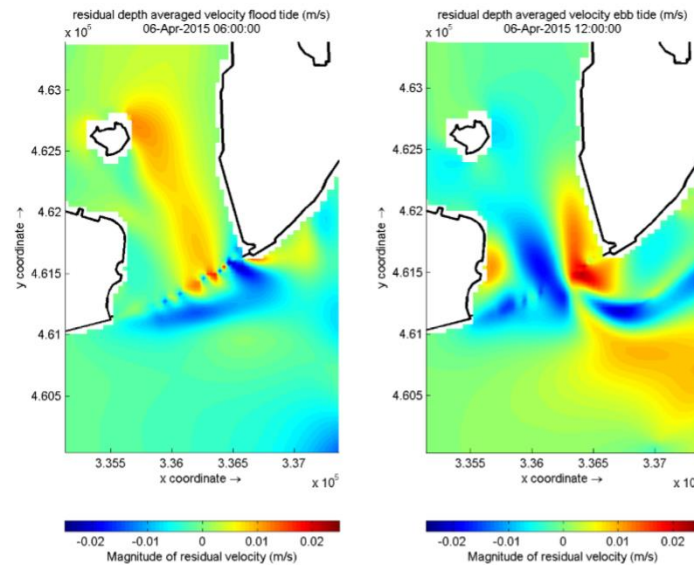


Figure 8: Magnitude of residual velocity due bridge during flood (left) and ebb tide (right).

Comparing the flood tide observations shows that velocity magnitudes have slightly increased in most of the upstream areas. However, at the vicinity of the bridge, extending from the south western border of Hulhule' island to about a third of bridge length, the velocities seem to have increased in both upstream and downstream direction from the bridge. On the other hand, and the central region of the channel shows reduced velocities in both upstream and downstream direction. The affected downstream distance in these two areas is about twice the length of upstream distance from the bridge. Additionally, at the western end of the bridge, near Male' island, the upstream velocities have reduced while the downstream velocities are slightly higher. Similar to our observations, Xiao Feng et al (2015) also showed that during flood and ebb tides, certain portions of the flow possessed an increased velocity region while a certain portion showed reduced velocity. These changes mostly coincide with regions in between piers and regions around piers respectively. Further research needs to be done to analyse the parameters impacting these changes.

Figure 9 shows the location of observation points selected to compare the current velocities and Figure 10 and Figure 11 shows the corresponding residual velocity profiles from those observation points. Figure 10 shows the residual velocity profile from the observation points located on the northern side of the bridge. A positive value indicates increased velocity due to bridge piers whereas negative value indicates reduced velocities. U1 represents a northern point located in between two piers 100 meters from the major axis of the bridge while U2 represents a

northern point located in line with a bridge pier 100 meters from the major axis. U3 and U4 represents a location about 500 meters and 1000 meters respectively from bridge axis. It can observe that U1 shows an increased velocity region for majority of the times since the graph lies slightly above the zero value. On the other hand, U2 shows a reduced velocity region since the graph lies well below the zero value for the majority of the times. Point U3 shows a much less variation in velocities compared to U1 and U2, although it shows a slightly reduced velocity region for the majority of time. Finally, the furthest point from bridge, point U4, shows almost no changes since the graph shows that the residual velocity is almost zero.

Figure 11 shows the residual velocity profile from the observation points on the southern side of the bridge located at the same distances as those in the northern points. As observed with U1, it can be seen that D1 shows an increased velocity region for majority of the times since the graph lies well above the zero value. On the other hand, as observed with U2, D2 also shows a reduced velocity region since the graph lies well below the zero value for the majority of the times. Point D3 shows a slightly increased velocity region for the majority of time. Finally, the furthest point from bridge, point D4, shows slightly increased velocities for the majority of the times, although few instances of reduced residual velocity followed by increased residual velocity can be observed. These observations are consistent with the findings of Hwei et al (2011) and Law (2015) where decreased velocity regions occurred in front and back areas of the piers while increased velocity regions occurred in areas in between the piers in both directions. In addition, the results Xiao Feng et al (2015) also indicted that low flow areas existed at locations around the bridge piers.

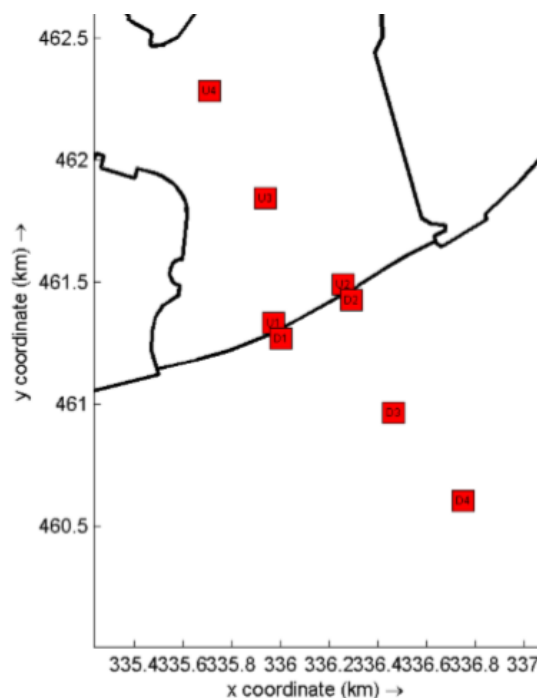


Figure 9: Locations of the observation points

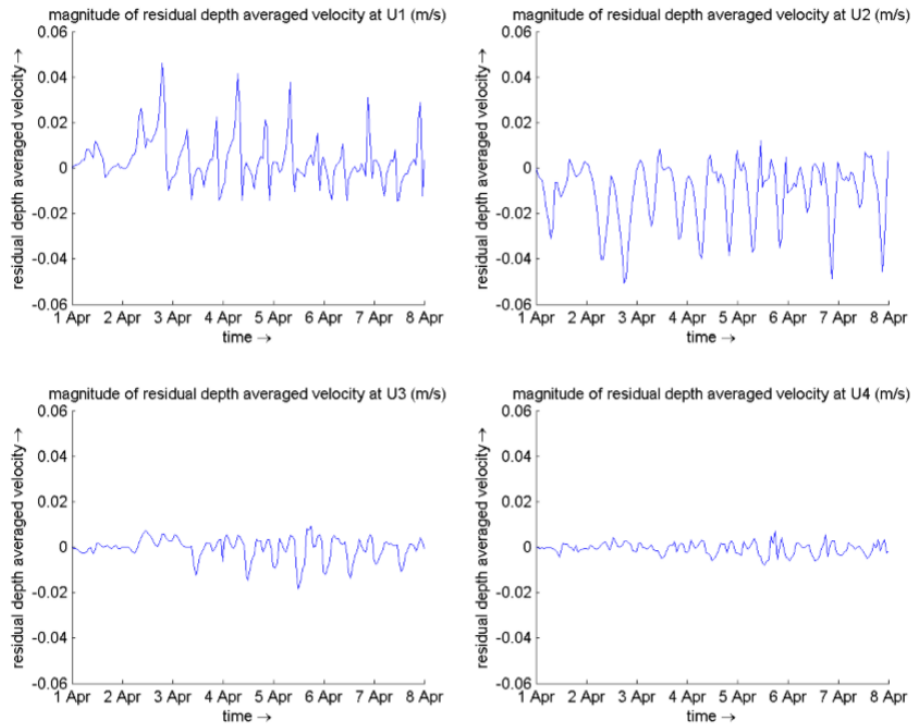


Figure 10: Magnitude of residual velocities at the northern points.

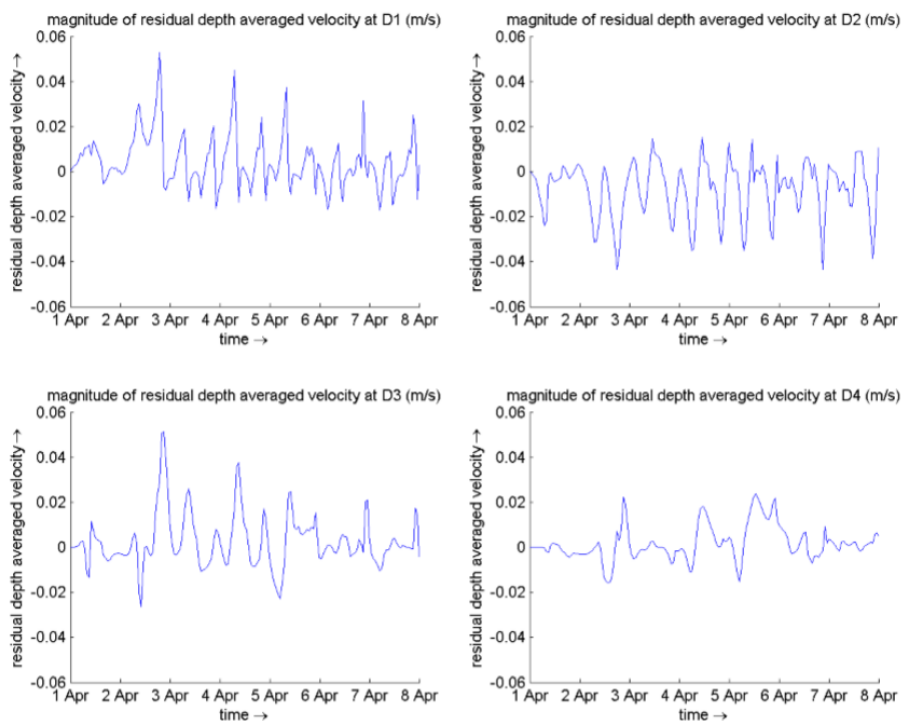


Figure 11: Magnitude of residual velocities at the southern points.

Based on the results from Figures 10 and 11, the majority of velocities reduces in the northern region (peak velocity reduced by 19.2% 500 meters from bridge axis) whereas a rise is observed in the southern region (peak velocity raised by 33% 500 meters from bridge axis). Eventually these variations become almost negligible in the northern region when the distance reaches one kilometre from the bridge axis while in the southern region slightly higher velocities persists one kilometre from the bridge axis. This implies that the degree of velocity variation from the southern region is much greater compared to the northern region and the overall velocity distribution in the northern region from the bridge axis shows a reduced velocity while the southern region shows an increased velocity. However, the velocities changes diminish to none past one kilometre in the northern region while in the southern region slightly higher velocities still persists beyond one kilometre. The observed impacted domain is somewhat consistent with the findings from previous literature. According to Hewei et al (2011), the hydrodynamic simulation of WeiYi Bridge in LiuZhou city, Guangxi province, China, showed that the impacted range was 150 meters on one side of the bridge while it was 1.8 kilometers on the other side. Xiao Feng et al (2015) also showed that the influence domain due to the Sea-Crossing Bridge in Quanzhou Bay was one kilometre in both directions. However, in contrary to the findings of this research, the findings from previous literatures indicates that over all flow velocity reduced in both directions due to the introduction of bridge. This could be due to the fact that the bridge for this research is located in an atoll environment where the hydrodynamical characteristics are thought to be more complicated compared to the bridge sites such as estuaries and rivers being modelled in previous literature.



Further studies are needed to accurately identify the model parameters impacting the results by tracking monitoring data and validating the results.

Conclusions

In this research, a Delft3D hydrodynamic model was set to study the hydrodynamic processes within the Gaadhoo Koa atoll pass. The calibrated spring and neap tidal levels predicted by the model are in good agreement with the observed water levels. The calibrated model was then used to simulate the effect of a water crossing bridge connecting the two main islands in the region. The simulation results indicated that the bridge piers resulted in a slight change in direction of flow. It was also found that the magnitude of flow velocity reduced around bridge piers and increased in between bridge piers. Furthermore, the overall velocity distribution in the northern region from the bridge axis showed a decreased pattern where peak velocity reduced by 19.2% 500 meters from the bridge while the southern regions showed an increased pattern where peak velocity raised by 33% 500 meters from bridge. Additionally, the observed impacted domain was found to be around one kilometre in northern region and slightly higher than one kilometre in southern region and the degree of velocity variation from the southern region was much greater compared to the northern region. Hence, it can be considered that the introduction of bridge piers has a considerable impact on the hydrodynamic conditions of Gaadhoo Koa channel. However, the model was not calibrated against currents and thus may not have yielded the most accurate current velocities. Further study is required to address these issues.

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DISTRACTED DRIVING WHILE DOING MOBILE PHONE CONVERSATION: A DRIVING SIMULATOR STUDY

Mohd Firdaus Mohd Siam¹,
Ahmad Azad Ab. Rashid²,
Nurulhana Borhan³
Mohd Khairul Alhapiz Ibrahim⁴

¹Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Selangor, Malaysia,
(Email:mfirdaus@miros.gov.my)

²Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Selangor, Malaysia,

³Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Selangor, Malaysia,

⁴Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Selangor, Malaysia,
Phone: +60389249200; Fax: +60387373994

Abstract: *Mobile phone is a very useful instrument to mankind whereby it can do lots more than make and receive telephone calls. Unfortunately, it has the potential to distract drivers in many ways. The aim of the study is to measure the distraction in term of participants' response time for different conversation task and driving scenarios using a driving simulator. In this study, 54 participants completed a secondary task (i.e. mobile phone conversation task) while concurrently performing the Detection Response Task (DRT) in a driving simulated environment. For driving scenarios comparison, three scenarios were used; free flow (40 km/h) with medium traffic volume, free flow (40 km/h) without traffic and traffic jam. For different conversation task, the contents of conversation were in emotional and factual conditions with hands-free and hand-held mobile phone. Overall, the results of this research showed that participants responded to lesser stimuli when dealing with more difficult conversation task. On another note, we also found that drivers were more distracted when dealing with more demanding tasks of using mobile phone (i.e. conversation tasks) as compared to baseline. In addition, participants attended the worst in term of stimuli and higher response time in traffic jam scenario as compared to other scenarios. Besides, the study discovered that novice drivers' group was identified to respond significantly faster rate than the experience drivers' group.*

Keywords: *Driver distraction; driving simulator; response time; road safety.*

Introduction

6,284 fatalities were recorded due to road crashes in year 2018 [1]. This alarming figure generate an average of 17 people killed every day. In worldwide, road traffic injury is the eighth leading cause of death and more than one million are killed every year because of road crashes [2]. Human errors are the main contributing factor whereby about 90% of the road traffic accident [3]. One of the severe and growing threat to road safety is driver distraction. Driver distraction can be defined as doing any task other than main task (i.e. driving) in which can divert driver's attention [4]. Driver distraction can impair the driver performance when drivers unable to allot adequate



attention to the main task during dangerous situation since they are involved in additional task that can cause to the impairment in the ability to drive safely [5]. Many literatures mentioned that driver distraction is well known as a causal factor in at least a quarter of vehicle accident [6,7,8]. This numbers could increase in the future due to the high usage of mobile phone while driving that has a high possibility to distract drivers.

Extensive studies from around the world have shown that driving distraction including mobile phone usage while driving increases the risk of crash involvement [9,10,11]. Other researches have shown that as little as 1 hour per month of cell phone use while driving increases a driver's crash risk 400–900% [12,13,14]. Cell phone use while driving has been reported to be more disruptive than ethanol intoxication [15]. Some studies revealed that there were negative effects on driver performance when talking on mobile phone while driving. These studies also summarised that hands-free and hand-held mobile phones usage yield similar impairment in performance as compared to normal driving (i.e. without mobile phone usage) [16,17].

Studies carried out concerning driver distraction specifically on mobile phone usage in Malaysia is still insufficient. One very limited experimental study using a driving simulator conducted by MIROS to measure the response time of several secondary tasks including texting usage while driving without specifying the character numbers concluded that 97% difference of texting response time as compared to baseline task [18]. Furthermore, a self-reported survey pertaining mobile phone usage while driving in Klang Valley has shown that 43.4% of drivers in Klang Valley used their mobile phone while driving, 61.9% while stopping at red lights and 53.6% used their mobile phone during traffic jams [19]. There were no specific accident data reported in term of type of fault related to driver distraction in Malaysia. Nearly related but arguable are careless driving, dangerous driving, dangerous turning, dangerous overtaking, driving too close, careless at entrance or exit and negligent signalling that have total percentage of 74.81% [20]. Approximately 176.5 million mobile cellular phones subscribed in Malaysia with ratio of 5.8 mobile cellular phones for each Malaysian in 2015. In addition, approximately 25,856 million Short Message Services (SMS) were sent in the same year [21]. With the advancement of smartphones and aforementioned figures, it is expected that will affect the usage of mobile phones while driving in Malaysian context. Seeing the critical issues of mobile phone usage as a source of distraction, MIROS conducted the study and published the paper that explains the methodology, data analysis and research findings. The study was aimed to measure the distraction in term of participants' response time for different mobile phone conversation task and driving scenarios.

Materials and Methods

Mixed method experiment and convenience stratified sampling was used in this study. Fifty-four participants, with twenty-seven males and twenty-seven female participants, took part in the study. All participants are right-handed drivers and have no specific knowledge or expertise about the study. Participants' ages range between 18 and 57 years old, with a mean of 31.47 years old. Participants took part in the study voluntarily, having read and signed a consent form that informed the purpose and procedures of the study. All participants are licensed drivers with an average driving distance of 20,478.27 km a year and an average driving experience of 10.42 years. Participants were selected among the staff at MIROS and the general public. Participants must be able to drive using automatic transmission. Two groups of participants were involved in the study

which are novice and experience drivers. Novice drivers are drivers who have the experience of driving less than 4 years and age between 18-24 years. While, experience drivers considered as more than 10 years driving experience and age between 30-59 years [22].

The MIROS Fixed-base Driving Simulator Cabin (CabinDS) was used in this study that utilised a platform from a second generation of Perodua Myvi 1.3L. The main components of the simulator are simulation software, steering wheel, pedals, transmission, full car cabin, LCD projector and screen, computer, video camera and sound system. Figure 1 illustrates the CabinDS system.

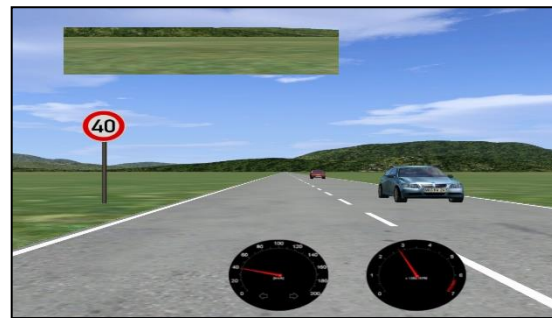


Figure 1: The integrated CabinDS system

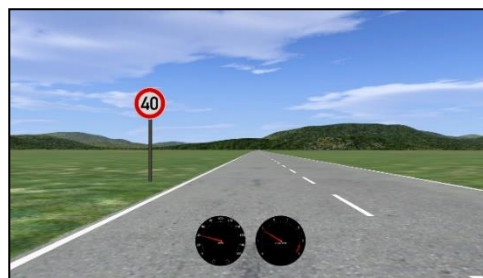
Three different driving scenarios were designed in this study, which were free flow (40 km/h) with medium traffic volume, free flow (40 km/h) without traffic and traffic jam. Figure 2 presents an illustration of the designated driving scenarios.



(a) Traffic jam



(b) Free flow (40 km/h) with medium traffic volume



(c) Free flow (40 km/h) without traffic

Figure 2 Illustration of the simulation scenarios

Driving was performed in a simulated traffic condition and the Detection Response Task (DRT) was used in a dynamic setting. DRT is one of the methods for measuring driver distraction [23]. Participants performed the driving task and the secondary tasks concurrently according to road conditions. Stimulus presentations for the DRT were controlled by the DRT software. Tactile DRT was used in the study. The stimulus on the DRT was presented at temporal intervals randomly, uniformly distributed between three and five seconds. Participants responded by pressing a microswitch attached to the right index finger on the steering wheel. The microswitch provided mechanical feedback indicating that a response has been made.

Mobile phone usage with conversation task was applied in the study as secondary task. For different conversation task, the contents of conversation were in emotional and non-emotional (i.e. factual) conditions with hands-free and hand-held mobile phone. There was an emotion induction procedure to induce emotional moods while converse using mobile phone. Participants were asked to read a short passage and watch short videos designed to make them angry, and then write for 12 minutes about a past experience that make them angry [24, 25]. Then, the conversation revolved around the past experience to preserve their anger. For the factual condition, questions and answers methods were involved in the conversation that related to the histories and facts. Every conversation took about 2 minutes to be completed. Figure 3 shows the conversation task that using hand-held mobile phone.



Figure 3: Conversation task using hand-held mobile phone as a secondary task

Each participant required approximately one and a half hours to perform the procedures of the data collection. Participants were given some instructions before executing the procedures. Participants were also asked to fill out the informed consent and personal detail forms. Safety briefing was given to participants before the data collection was conducted. Then, participants were subjected to simulator sickness screening prior to the experiment. The purpose of the screening was to ensure participants were well, fit and capable to drive the driving simulator. Next, they were asked to perform training and familiarization session for secondary task, driving simulator and the DRT device. Participants were not given time limit during this training session but the session was stopped when participants felt comfortable performing the tasks. During the actual data collection

session, participants needed to complete all tasks and allowed to stop the experiment without coercion. After that, participants were also subjected to post simulator sickness screening after they have completed the actual data collection. After completion of all tasks, participants were interviewed about their driving experience. Then, participants were thanked and rewarded for their participation.

Results and Discussion

Figure 4 shows the percentage of stimuli participants responded to when doing the secondary tasks for three respective driving scenarios. Participants responded most to the stimuli presented in the baseline condition – 96.9% in the 40 km/h situation with relative medium traffic volume, marginally 0.5% lower in the 40km/h situation without traffic, and slightly lower in the traffic jam scenario. The percentage of stimuli responded were lower than the baseline in the other four conversation related conditions. Inspection of Figure 6 suggests that, within each traffic situation, participants responded to the least stimuli during the emotional conversation without holding the phone, followed by emotional conversation while holding the phone. Participants responded relatively equal frequent to the other conditions involving factual conversations.

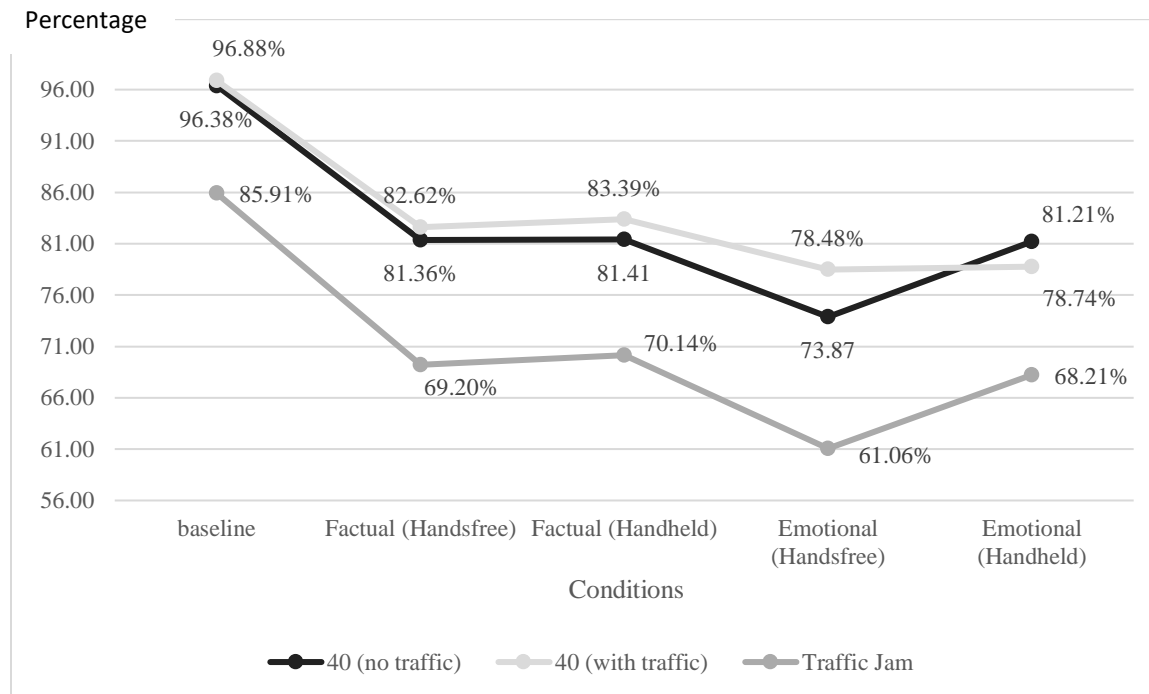


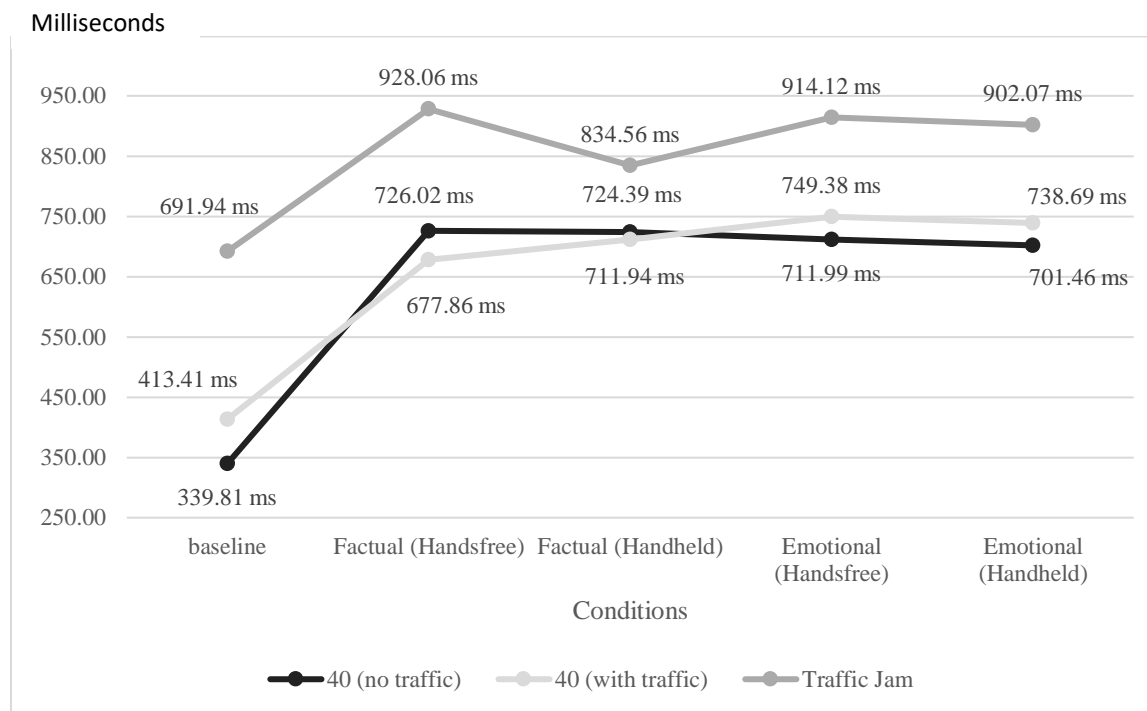
Figure 4: Percentage of stimuli responded for each conversation related condition based on driving scenarios

To proceed with the analysis, the result of response times were subjected to mixed factorial repeated-measures ANOVA procedure to study for mean differences of response times with respect to various conversations, driving scenarios, and any potential interaction. As Mauchly’s test indicated a violation to the assumption of sphericity for the main effect of conversation conditions, $X^2(9) = 24.84, p = .001$; the associated degree of freedom in the ANOVA was corrected



using Greenhouse-Geisser estimates of sphericity. The results of the test revealed a significant main effect of conditions on response times, $F(3.21, 170.08) = 41.80, p < .001$. Further, simple contrasts revealed that response times for all conversation conditions are significantly higher than the baseline, $F_{baseline vs. factual (handsfree)}(1, 53) = 115.31$; $F_{baseline vs. factual (handheld)}(1, 53) = 93.27$; $F_{baseline vs. emotional (handsfree)}(1, 53) = 89.13$; $F_{baseline vs. emotional (handheld)}(1, 53) = 82.89$; all pairs had $p < .001$.

Main effect of driving scenarios on response times was also significant, $F(1.70, 90.28) = 89.86, p < .001$; with significant contrasts between traffic jam and both 40 km/h scenarios, $F(1, 53) = 120.51, p < .001$; and $F(1, 53) = 102.04, p < .001$; respectively. There was also a significant interaction effect between conversation conditions and driving scenarios, $F(5.79, 306.64) = 2.60, p = .02$ (Greenhouse-Geisser corrected). Figure 5 depicts these results. Response times for traffic jam scenario were longer than both 40 km/h driving scenarios across all conversation conditions.



The analysis continued with investigation involving between-subject variables – gender and age group. The age group was defined as novice (less than 4 years driving experience and age between 18-24 years) and experience (more than 10 years driving experience and age between 30-59 years).

The main effects of gender and age group on response times during conversation conditions were both non-significant: $F(1, 52) = 2.20, p = .14$ for gender; and $F(1, 52) = 3.87, p = .06$ for age group. The only interaction effect involving response times during conversation was only between age group and conversation conditions $F(3.11, 161.90) = 3.51, p = .02$. The remaining pairs had no significant interactions: between gender and traffic situations $F(1.71, 89.12) = 2.38, p = .11$; between gender and conversation condition $F(3.20, 166.24) = .36, p = .80$; and between age group



and traffic situations $F(1.71, 88.74) = .34, p = .68$. Mean and standard deviations for each condition pair are in Table 1.

Table 1: Summary of response time means based on gender and age group for conversation related conditions.

Scenario	Character Number	Adjusted Response Time, <i>M</i> (<i>SD</i>) milliseconds			
		Male (<i>N</i> = 27)	Female (<i>N</i> = 27)	Novice (<i>N</i> = 28)	Experience (<i>N</i> = 26)
40 km/h (no traffic)	Baseline	320.86 (141.62)	362.90 (138.99)	334.31 (154.52)	350.03 (126.43)
	Factual (HF)	707.97 (387.94)	755.15 (289.49)	611.35 (304.53)	861.01 (333.32)
	Factual (HH)	667.49 (290.75)	787.72 (228.65)	644.35 (255.28)	817.27 (252.17)
	Emotional (HF)	632.58 (281.92)	787.59 (370.45)	684.30 (364.35)	737.85 (305.68)
	Emotional (HH)	668.33 (306.9)	727.05 (347.12)	649.50 (278.63)	749.59 (368.61)
40 km/h (with traffic)	Baseline	412.21 (202.78)	416.83 (187.57)	388.57 (193.22)	442.46 (193.59)
	Factual (HF)	672.15 (283.11)	688.61 (211.69)	617.31 (250.46)	748.30 (230.46)
	Factual (HH)	668.74 (307.87)	758.40 (314.05)	598.59 (268.96)	837.40 (310.82)
	Emotional (HF)	725.75 (447.16)	766.80 (336.84)	669.49 (321.81)	828.97 (448.66)
	Emotional (HH)	683.88 (294.92)	784.21 (303.98)	706.60 (278.11)	763.60 (326.65)
Traffic Jam	Baseline	628.37 (286.57)	755.80 (338.06)	691.91 (312.26)	692.27 (328.21)
	Factual (HF)	834.22 (389.94)	1029.33 (400.22)	899.45 (425.03)	966.60 (384.37)
	Factual (HH)	775.65 (293.07)	926.73 (371.32)	729.37 (295.84)	982.38 (340.59)
	Emotional (HF)	866.85 (255.96)	981.35 (351.06)	871.41 (298.58)	980.84 (317.25)
	Emotional (HH)	876.56 (332.02)	932.38 (303.51)	874.23 (355.29)	937.04 (271.44)

Note: HF and HH refer to hands-free and hand-held, respectively

As mentioned in the literature review, drivers can get distracted by using mobile phone in several ways while driving. This study used DRT to measure the effects of driving demand and engagement in secondary tasks on driver attention. The secondary task involved conversation task in which emotional and factual conditions were induced during the dialog session between researcher and participants. This task was using hands-free and hand-held mobile phone. The current experimental setup was found to have successfully captured the response time and measured the driving distraction among the participants. A vital finding is that all conversation conditions (i.e. emotion and factual conversation using hands-free and hand-held) are significantly higher than the baseline (i.e. without doing secondary tasks). However, there were no significant



difference between hands-free and hand-held mobile phone, also between emotion and factual conversation. This result is aligned with the existing studies, in which indicate that the use of hands-free and hand-held phones yield similar impairment in driving performance as compared to normal driving [26, 27]. In addition, the finding from the study seem to support the results from other study that revealed mobile phone conversation diverts drivers' attention away from components of the driving task that require explicit attentional processing, resulting in longer response times [28]. Strayer and Johnston (2001) also support our finding, in which any mobile phone conversation regardless of emotional conditions negatively affects driving performance [29].

Another important finding was that drivers' engagement in both secondary tasks while driving in a challenging driving scenarios increased their reaction time to stimuli, which indicate higher level of distraction. Drivers were found to be distracted the most when driving in a traffic jam, compared to a free-flowing traffic scenarios. In other words, the level of distraction due to mobile phone usage is worsen by a demanding driving scenarios. Although a previous study reported no relationship between the frequency of distracted driver behaviours and amount of traffic [30], our result could indicate potentially higher risk of distracted driving in certain traffic conditions. This risk can be even higher when the secondary tasks are more complex in nature as indicated by the significant interaction effects on participants' response times.

In this study, comparing the response times between experience and novice drivers revealed an interesting finding. The novice group was found to respond to the stimuli at significantly quicker rate than the more experience group. This finding was unexpected mainly because being more experienced was established by previous research as a factor that is associated with a greater degree of adaptation to increasingly complex driving environments [31]. A possible explanation for this might be that the effect of experience is not necessarily the same on driving performances, as compared to the level of distraction. In other words, being quicker in responding to stimuli might not guarantee a better driving performance among the novice group, vice versa. Interestingly, previous study conclude that experience is not a factor that can solve the safety issues related to distracted driving caused by dual tasking, mainly due to the complexity of the primary task at hand (e.g., driving a moving vehicle) [32].

Conclusion

In a nutshell, the objectives of the study were fulfilled whereby to measure the distraction in term of participants' response time for different conversation task and driving scenarios using a driving simulator. The findings of this research indicate that drivers were more distracted with the more demanding tasks of using mobile phone (i.e. conversation task) as compared to baseline. Among three driving scenarios, participants attended the worst in term of stimuli and higher response times in traffic jam scenario. Besides, novice group was identified to respond significantly faster rate than the experience group. This study shows that using mobile phone conversation whilst driving is considered as distracted activity that possibly raises the risk of crash.

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IMPLEMENTATION SELECTED TOOLS OF LEAN MANUFACTURING

Mohd Adzrie¹
Elcy K
Joselyn R. M
Na Mohd-Lair
Chai F. O

¹Mechanical Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah (mohdadzrie@ums.edu.my)

Abstract: *This study aims to understand the general perspective of industrial company operating in Sabah, regarding the implementation selected tools of lean manufacturing. The objectives of this paper are to evaluate the implementation of lean manufacturing and its tools among manufacturing company located in Sabah. Apart from that, it will also identify the problem and factor in implementing lean manufacturing tool as well as the benefits experienced after the adoption of lean manufacturing tools. The scope covers manufacturing company of any types of industry that is actively operating in Sabah, regardless of size. Instrument of study is a survey questionnaire that contains open and closed ended questions, sent out to target respondents. Data analysis is done using descriptive statistics to explain the trends in dataset and Cronbach's Alpha to test the internal reliability of the instrument. This study finds significant evident of the implementation of lean manufacturing and its tools among manufacturing companies in Sabah, as well as the problem faced in implementation, factors of implementation and benefits experienced after the adoption of lean manufacturing tools.*

Keywords: lean manufacturing, lean manufacturing tools

Introduction

The current strategy used by most companies nowadays is a traditional manufacturing approach that focused on producing a set number of products each period and kept them reserved in the inventory in case of unexpected demands or shortages. This caused companies to hold a large amount of inventory and overproduction. In addition, employees only do jobs/works that are assigned to them without any systematic management, in which this particular method causes employees to perform unnecessary works [1]. This affects the product development of the company and cause slacks which therefore, lead to failure in tracking manufacturing process in details, in terms of activities, and affects the ways of information transmission including how and when the next step should be taken. This is an indication that approaches in management has a vital role to the companies' production line.

In conjunction, Malaysian Productivity Corporation (MPC) has been introducing lean management since 2011 to various organisation and since then, MPC has held seminars which attended by 1,587 participants from 376 companies. Government departments and companies in the State has been advised to consider implementing the lean management system in their organisation [2].



Most study that have been done based on lean manufacturing implementation are focused on peninsular region. Wong et al. (2009) examined the adoption of lean manufacturing in the Malaysian electrical and electronics industry [3]. Noraini Nordin et al. (2010) investigated the lean implementation in Malaysian Automotive industry [4]. Ng et al. (2015) studied the analysis of lean manufacturing tools in Malaysia's manufacturing industry [5]. On the other hand, review made based in East Malaysia, Sabah to be specific is still lacking. Therefore, there is a gap in reviewing the level of understanding and status of implementation of lean in manufacturing companies which originates in Sabah are still unknown although it has been long introduced in Sabah.

While some may have perspective about lean concepts in general, there has been less review about the status of implementation of specific tools listed in lean manufacturing. Acknowledgement in implementation of lean tools and the characteristic such as problem in implementation, its factors and benefits among Sabah Manufacturing industries are still not identified. Due to lack of support and advices, these organisations might not be able to experience lean manufacturing's benefits.

Literature review

Lean manufacturing has a very long history, depending on how lean is defined. Although, the first person to truly integrate an entire production process was Hendry Ford when he first design Model T Ford. He puts together many ideas regarding production line which soon, came to invention of the Toyota Production System by Kiichiro Toyoda, Taiichi Ohno and others at Toyota [6].

Generally, Toyota is known as the birthplace of lean. Due to shortage of capital and resources, overproduction had to be avoided thus Pull came to support production scheduling. Product/service is produced at the pull of customer, not pushed through the organisation without the concerns of customer's need. Taichii Ohno introduced the concept of Total Production System (TPS), which was widely referred as just-in-time (JIT) manufacturing in the 1980s. Lean is developed principally from the TPS but including many other sources. It can be said that continuous learning aspects of TPS have made it a core concept of lean [6].

Lean manufacturing also known as lean production or simply "lean" is a business philosophy applied in managing companies as it implements several approaches and appropriate tools in order to achieve improvements that allows companies to reduce cost, improve processes and eliminate waste to increase customer satisfaction. In other words, it is the set of tools that assist in the identification and reducing of waste in design, manufacturing, distribution and customer service.

Problem in implementation

A case study by Abhay et al (2014) identified several barriers based on their observation in a manufacturing organisation [7]. Their observation listed significant barriers such as poor training, lack of awareness among the staff, lack of communication, and gap between top management and employees. In conjunction, according to One et al (2005), barriers in lean tools implementation are lack of commitment and leadership from top management, lack of proper training and education as well as resistance from the employees. In addition, they also included non-conducive environments in the adoption process as one of the challenges [8].



Atif Qamar Malik (2014) observed more details obstacles that raised during the process of implementing lean tools, which were workers only do a minimum effort in doing tasks, workers did not follow the guidelines given during the training programme, and management is reluctant on investing in employees' training [9].

Factors of implementation

Nowadays, lean manufacturing tools is increasingly recognized as a management technique that enhances productivity and competitiveness [10]. In India particularly, the small-scale industries (SSI) contributes a vital segment of the Indian economy in terms of industrial production, exports, employment and creation of an entrepreneurial base. Simply, small manufacturing firms face massive challenges in this world that is always transforming. Hence, the pressure to rapidly introduce new creation in an increased quality and reduced cost has led them to find a solution to improve their performance [11].

Due to tough competition worldwide, rejection/error in manufactured parts at various stages of manufacturing must be avoided in today's production line. Manufacturing industries are heading towards the direction of zero-defect production. Varun Kumar (2016) further added that producing high quality of products and services is listed as one of the key concerns in order to compete in the global markets [12]. They further explained that production of product in 100% without any defect is not only a challenge, but also a necessity for companies. This forces company to put great effort on preventing faulty products and services by any means, before customers received them. Consumers expect highest quality, reliable delivery and competitive pricing from the manufacturers. This challenged companies to look for new strategy to save costs, develop employees to face future obstacles and develop new culture at work place.

Benefits of implementation

It is important to note that, lean approach is to produce more while consuming less. In conjunction, a study by Wójcik et al (2015) on the impact of lean manufacturing tools to the company's operation improvement, stated that the following phenomena are noticeable: an increase of employee's motivation, development of a company's organisational culture, reduction of costs associated with production of products as well as improvement in products quality. The study also concluded that waste in term of waiting is eliminated [13].

The benefits of lean implementation are the increased in customer satisfaction, workplace safety, efficiency and quality. Previous study noted that it reduced the cost of doing business, reduced inventory as well as improved employee morals. These are the benefits that are cited frequently Lean manufacturing are popular and widely applied to improve operational performance by reducing inventory and increasing quality levels [14]. Marodin (2018) also found that lean manufacturing practices have a positive impact on quality improvement in a way that it reduces process variability by standardizing work methods to ensure the availability of equipment, materials and trained workers [14].



Methodology

A questionnaire was developed to collect data for this study, which consist of two parts; (A) the background information of the respondent and the company itself, and (B) the lean manufacturing implementation. A five-point Likert scale was also included which identifies the problem face, factors of implementation and benefits obtained from the implementation of lean manufacturing.

The sample space was obtained from the database of Federation of Malaysian Manufacturers (FMM) and Federation of Sabah Industries (FSI) which only target on manufacturing companies in Sabah. Contact information, such as email address and phone number of respective companies is obtained from the official website. Questionnaire will be distributed, and a period will be given for the data collection. Main method of questionnaire distribution is through email however other alternative methods will be carry out to increase the response rate.

Data gathered will be processed and summarized by using descriptive statistics as well as analysed using Cronbach's Alpha to measure its internal reliability using SPSS software. Descriptive statistics are tool that assist in organising and summarising data. To study the pattern that emerges from the data, descriptive statistics will be used to describe and summarise the data in a meaningful way. Data will be presented in a form of tables, graphs bar charts and frequency plots that detail the responses received.

A common first step in data analysis is to summarise the information of variables, such as measure of central tendency and measure of dispersion as they related to each other. Measure of central tendency is related to the measure of average value of the sample. It consists of mean, median and mode. While, dispersion refers to the spread of the value around the central tendency, specifically the mean value.

For the questions especially the form of Likert scale, Cronbach's alpha is the common measure of its internal consistency or reliability. Reliability refers to the extent of consistency produced by a scale, for a repeated measurement. Having a measure with good reliability signifies the internal validity and ensures that the data obtained can be trusted to represent the participant's performance. The general practice value of Cronbach's Alpha, α is approximately 0.70, yet it can be as low as 0.6. Hence, $\alpha \geq 0.70$ is sufficient to assume that it is reliable [15].

Results

A total of 25 responses were obtained, which 15 of them was responded through the email, 6 from the online survey and 4 obtained from the company visit. The responses were representative of the type and spread of industries within Sabah, with West Coast being the location of most of the companies involved in manufacturing operations. Most respondents were representatives of in the position of engineers, with an approximate number of 40% from the respondent pool. The distribution of the manufacturing company included in this study among the various industries based on the product they manufactured portrayed that 28% of the manufacturing company belong to the Electricals & Electronics industry, followed by construction industry (20%). The respondents were mostly from small companies with less than 50 range number of employees which exhibits 40%, closely followed by those from big companies with more than 100 employees.

To further verify the extent of lean implementation in Sabah, the respondents are asked about their knowledge involving lean manufacturing. This is important to know their knowledge and awareness about lean manufacturing in general. Figure 1 shows the percentage of lean manufacturing awareness.

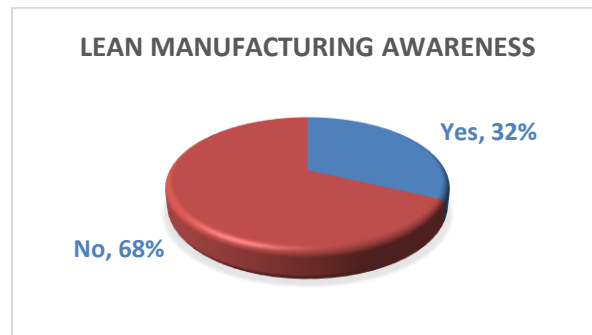


Figure 1: Lean manufacturing awareness (N=25)

Out of 25 total respondents, 8 acknowledged that they had a basic understanding of lean manufacturing. 68% (17 respondents) have no knowledge and no experience with lean manufacturing. This show that the awareness of lean manufacturing is still lacking.

To achieve the main objective of this study, respondents were asked about lean manufacturing implementation in their company. Questions asked about their implementation, period of implementation and tools that they have been implementing. The adoption of lean manufacturing among the manufacturing companies is shown as below.

Table 1: Lean implementation status based on location (N=25)

Location (Division)	Yes	No
West Coast	$\frac{4}{13}$	$\frac{9}{13}$
Kudat	$\frac{0}{1}$	$\frac{1}{1}$
Sandakan	$\frac{1}{2}$	$\frac{1}{2}$
Tawau	$\frac{1}{3}$	$\frac{2}{3}$
Interior	$\frac{3}{5}$	$\frac{2}{5}$
Labuan	$\frac{1}{1}$	$\frac{0}{1}$
Total	$\frac{10}{25} = 40\%$	$\frac{15}{25} = 60\%$

Among 25 manufacturing companies, only 10 of them or 40% implement lean manufacturing, which is contributed by 4 companies out of 13 from the West Coast division, 1 out of 2 companies from Sandakan division, 1 out of 3 companies from Tawau division, 3 out of 5



companies in Interior division and lastly a company from Labuan. Majority of the respondents (15 out of 25, 60%) do not apply lean manufacturing in their company.

Table 2: Period in engaging lean manufacturing (N=10)

	Frequency	Individual %	Cumulative %
Lean manufacturing implementation period			
2-3 years	6	60	60
More than 3 years	4	40	100

This survey investigated the number of year that the respondents' company have been involved in lean manufacturing to indicate the maturity in the field. It can be observed that more than half of the respondents (60%) are engaged in lean manufacturing for 2-3 years, while 40% of them are involved for more than 3 years.

Table 3 shows the frequency of lean manufacturing tools that have been implemented in 10 companies, distributed with respective industries that the companies are involved in. The most used tools are 5 S and KPI which were applied by a total of 8 manufacturing companies.

Table 3: Distribution of lean manufacturing tools based on the type of industry

Lean Manufacturing Tools	Industry types					Total implementation
	Construction	E&E	Metal	F & B	Agriculture	
5S	///	/	/	//	/	8
Bottleneck Analysis	/		/			2
Continous flow		/				1
Heijunka		/		/		2
Hoshin Kanri		/		/		2
Jidoka				/		1
JIT		/	/			2
Kaizen		/	/			2
KPI	///	//		/	//	8
OEE	/	/		/	/	4
PDCA	/	//	/			4
Root Cause Analysis	/		/			2
SMART Goals	/	/		/		3
Standardized work		/		/		2
Tact Time	/			/	/	3
TPM	/			/	/	3
Value Stream Mapping				/		1
Visual factory				/		1



Table 4 displays the value of Cronbach’s alpha coefficient of all the items is within the range of 0.774 to 0.813. This indicates that all the items have a good degree of internal consistency. Furthermore, the “Cronbach’s Alpha if item deleted” column estimates the value of Cronbach’s Alpha if that particular item is deleted. As shown in the table, some of the values in that columns are higher than the Cronbach’s Alpha hence that item can be removed to improve internal consistency for more accuracy.

Table 4: Cronbach’s Alpha reliability test (N=10)

No	Variables	Cronbach’s Alpha if item deleted	Cronbach’s Alpha
Problem faced in implementing lean manufacturing tools			
1	Lack of training	.604	.774
2	Lack of resources	.707	
3	Resistance from staff/employees	.610	
4	Adoption/maintenance is complicated and costly	.845	
Factors of implementing lean manufacturing tools			
5	Pressure from top management	.675	.783
6	To increase business opportunities	.683	
7	Desire to employ world best practice	.747	
8	The drive to focus on customers satisfaction	.649	
9	To reduce waste in production	.899	
Benefits of implementing lean manufacturing tools			
10	Helpful in increasing business opportunities	.781	.813
11	Organisation become more productive	.739	
12	Any operation become more effective	.739	
13	Efficiency in meeting customer satisfaction increased	.806	
14	Waste in production decreased	.826	

Discussion

Out of 25 respondents, only 10 of them implemented lean manufacturing in their company. Those companies were mainly located in the West Coast division, to be specific Kota Kinabalu. This is because of Kota Kinabalu being the capital city and the economic centre of the Sabah. Although majority of the companies still have lack of awareness and do not implement lean manufacturing and its tools, it is a fair conclusion that companies around Sabah had already been implementing lean manufacturing. This statement is proved by the result; 3 companies from West Coast division, 1 from Sandakan division, 1 from Tawau division, 3 from interior division and 1 from Labuan. Kudat division on the other hand has only one representative because Kudat is mainly focused in tourism sector. In addition, majority of the companies have already been implementing lean manufacturing for a period of 2-3 years. However, by looking at the number of companies that have not implemented lean manufacturing, it indicates the need to increase lean manufacturing awareness and encourage more company to implement it.

With 5S and KPI being most applied tools, each company implemented at least 2 lean manufacturing tools in their company. 5S was viewed as the easiest lean strategy to implement as 5S is the gateway for companies to begin the transformation to lean manufacturing. Implementing



the 5S strategy sets up the change in culture required for structured continuous improvement. 5S allows for a visible and disciplined change where employees can recognize a lean manufacturing method in action that focuses on workspace organisation and the elimination of non-essential equipment [16]. While, KPI is highly implemented because it can be used in all areas of business as it is a measurable value applied to business objectives. In simple words, KPI can tell whether the company is moving forward or backward, which is useful in the decision-making process and help to drive the growth of the company forward [17].

The least applied tools are visual factory, value stream mapping, Jidoka, and continuous flow. This may due to high level of difficulty in implementing these tools, which reduces the chance for success. Among all the mentioned tools, continuous flow has been listed as the most difficult lean tools to implement based on [16].

However, it is important to note that all industry have been implementing at least 2 tools of lean manufacturing, which indicates that the industry is rapidly involved in lean manufacturing and is not restricted to using only 1 tool in their company.

Problem faced in implementing Lean Manufacturing

Lack of resources has the highest agreeability which can be further postulated as financial constraints that the company may face, due to company size as majority of the respondents come from small companies. It is also important to note that there is a significant agreeability that companies faced problem in implementing lean manufacturing tools due to lack of training and resistance from staffs. Question number 4 is removed in order to improve internal consistency if item deleted, based on the Cronbach's alpha result.

Factors of implementing Lean Manufacturing

For factor of implementing lean manufacturing tools, the highest agreeability are due to pressure from top management and the drive to focus on customers' satisfaction. These two factors correlate with each other as to compete in today's rapidly transforming worlds, manufacturing companies face massive challenges hence the pressure to introduce new techniques is necessary to improve company's performance [11]. Identifying consumer's needs and demands are the first principle of lean manufacturing in order to strive for perfection. Question 9 is removed in order to improve internal consistency if item deleted, based on the Cronbach's alpha result.

Benefits gained in implementing Lean Manufacturing

There is a significant evident that companies benefit from implementing lean manufacturing tools however this statement is arguable by looking at the amount of "neutral" and "disagree" responses. Even though some company agree that lean manufacturing tools implementation are beneficial in their company, the same amount of neutral or unsure responses were received. This may be due to lack of knowledge and awareness of the representative regarding the company's performance and productivity. Other reason such as incorrect implementation, might as well contribute to the amount of neutral and disagree responses. Question 14 is removed in order to improve internal consistency if item deleted, based on the Cronbach's alpha result. Figure 2 provides a graphical overview of the data collected.

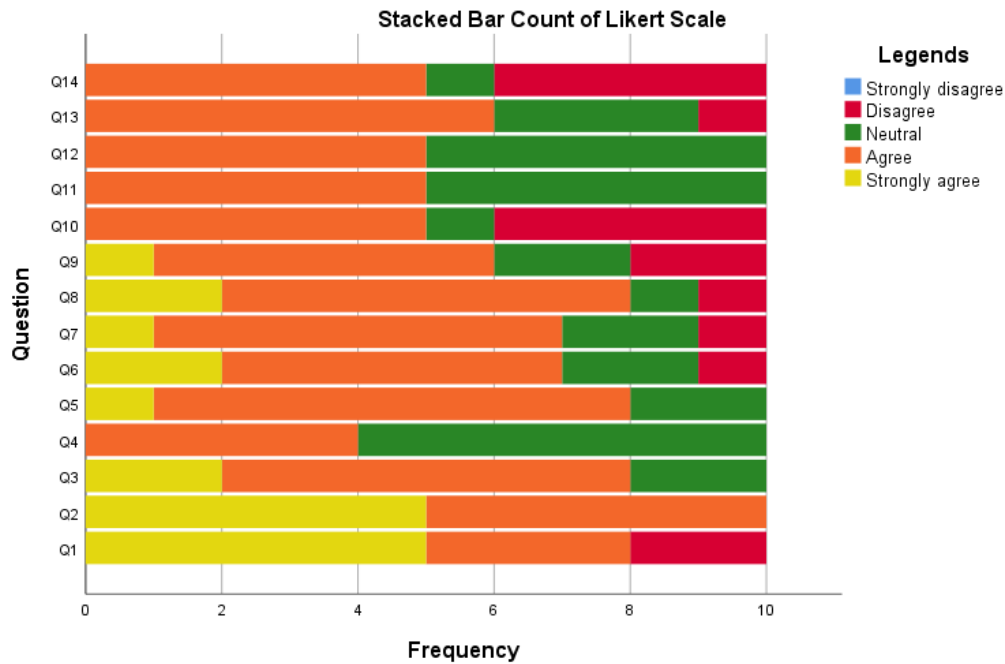


Figure 2: Stacked bar chart for frequency of response in Likert scale data

Conclusion

Study of lean manufacturing implementation assists individuals in understanding how companies are pursuing improvements initiatives in real world situation. It explores how lean concepts are being implemented and applied in a practical setting rather than detailing an idealistic situation. Based on the data collected, conclusion can be used to help identify the strengths and deficiencies. This study benefits companies that participate in this study, especially companies that have not implement any lean tools, to learn and educate themselves from companies that have already engaged in lean tools. This research is valuable because it gathers data from both lean and non-lean facilities in real world, allowing an evaluation of effectiveness and direction in implementing lean manufacturing. Future research and development can relate to the ideas stated and studied here for new, improved and more efficient manufacturing system especially around the scope of study.



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A REVIEW OF IMPLEMENTATION OF 5S IN SME

Mohd Adzrie¹
Chai F. O
Eley K
Joselyn R. M
Na Mohd-Lair
M.A. Madlan

¹Mechanical Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah (mohdadzrie@ums.edu.my)

Abstract: *There have been many studies carried out on Lean manufacturing implementation in larger organizations with specific focus such as sig sigma, kaizen, just-in-time and many others lean tools. Many of these studies shows that Lean manufacturing implementation has driven the organization with tremendous improvement. Lean implementation among Small and Medium Enterprises (SME) has not been so extensively researched or even implemented among the SME companies. This project was a case study which attempts to bridge this gap by implementing the Lean manufacturing principles in SME with a perspective of identifying the benefits of the implementation. A company was chosen and agreed to took part in this case study. After getting the agreement from the company, a selected lean manufacturing tool (5S practices) was implemented. This aim of this project is to determine the outcome after the implementation of 5S practices.*

Keywords: *lean manufacturing, 5S, SME*

Introduction

Many of the large manufacturer has taken part in lean implementation in order to improve their performance. Lean manufacturing is one of these initiatives that focuses on the cost reduction by eliminating wastes. Therefore, the small and medium enterprises may need to practice the lean principle in order to compete with the larger manufacturer.

Research at Lean Enterprise Research Centre (LERC) U.K. indicates that for a typical manufacturing company the ratio for activity could be broken down as value added activity-5%, non-value-added activity (waste)-60% and necessary non value added activity-35%. This implies that up to 60% of the activity at a typical manufacturing company could potentially be eliminated. All Lean manufacturing tools are not possible to implement in small medium enterprise company because of limited resources in terms of finance, infrastructure and work force. The 5S, potential Lean manufacturing tool selected to be applying for performance improvement of company and related environmental investigations, environmental performance evaluation, environmental labelling, life cycle assessment, environmental communication, environmental aspects of product design and development, environmental aspects in product standards, terms and definitions, greenhouse gas management and related activities, and finally, measuring the carbon footprint of products.



This study focuses on the manufacturing industry. The purpose of this project is to describe the analysis of the case company's productivity before and after the implementation of lean philosophy, which also aimed to improve productivity of the company by using lean principle.

The research questions were set as follows:

- a) What is the current level of lean implementation of the company?
- b) How can lean manufacturing implementation benefits the company?

The research questions are addressed through literature findings and empirical analysis. The empirical data was collected from survey and included observation, and interviews with employees. The project is structured as follows: for the background of the empirical study, the literature on lean manufacturing and lean manufacturing development is reviewed. Then, the research method is explained. The case description and analyses are presented in the results section. Finally, the outcomes are discussed from theoretical perspectives and the study conclusions are presented.

Although lean manufacturing implementation was originated from manufacturing origin, but it also has also been applied in many other sectors, including, for example, software, construction and healthcare. Over the years, the body of knowledge on lean manufacturing and related areas has expanded. According to Jasti et al. (2014), most of the studies have been conceptual [1]. A conceptual review of lean production was presented in Papadopoulou (2005). The review covered a few aspects in terms of definitions, the key elements, and criticism of lean manufacturing [2]. According to Pettersen (2009) a combined review of the conceptual and practical issues of lean production [3]. Finally, a review of empirical research on lean manufacturing was conducted by Sohal et al. (1994) [4].

Literature review

The focus of lean manufacturing was to reduce the cost and to improve productivity by eliminating wastes or non-value-added activities. Womack and Jones in their book "Machine that changed the world" (1990) argue that the adoption of lean approach will change almost everything in every industry- choices for consumers, the nature of work, and fortune of industry by combining the advantages of craft and mass production. The lean approach consists of various practices, which aim to improve efficiency, quality and responsiveness to customers [5].

Implementation of 5S

The strategy devised by Hirano depicts that the implementation should be carried in such an order that the simpler and basic methodologies should be installed first. Hirano describes the sequence of implementation in the following Figure 1.

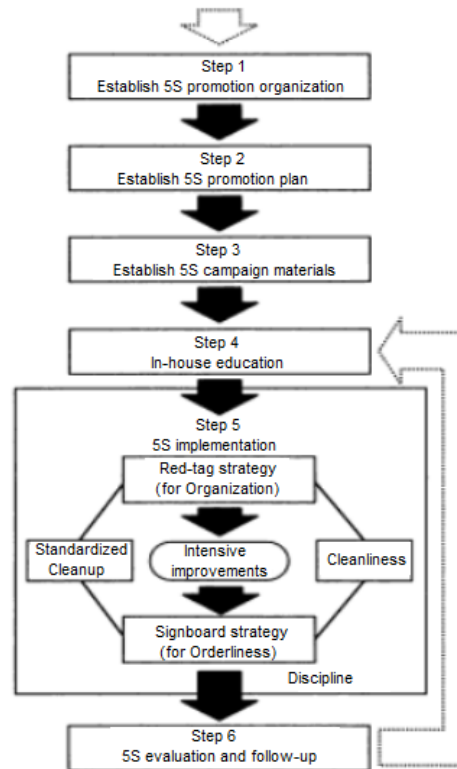


Figure 1: Hirano's 5S Implementation Strategy

Problem in implementation

According to Womack et.al. (1996), in order to implement the concept of lean manufacturing successfully, many researchers emphasize commitment by top management and the companies should utilize strong leadership capable of exhibiting excellent project management styles. These qualities would facilitate the integration of all infrastructures within an organization through strong leadership and management vision and strategy [6].

Good leadership ultimately promotes effective skills and knowledge enhancement amongst its workforce and minimizes the non-value activities in order to eliminate the wastes. The manager should also work to create interest in the implementation and communicate the change to everyone within the organization, specifically, the needed information related worker in shop floor should be updated respectfully. Worley and Doolen (2006) stated that, the failures attributable to management support shared some common characteristics: First, executive management must provide employees with more information on the lean manufacturing initiative and why it is needed. Second, executive management must provide employees with resources such as time and materials to allow the employees to successfully participate in the lean manufacturing effort. If employees make plans for changes but do not see results, discouragement may occur, and future lean manufacturing activities may not be supported. Though it is often desirable to drive change



from the factory floor, it is important that a transition to lean manufacturing be driven by the executive management team. Of course, while some success was achieved at the customer level, more success was realized from the employee perspective. Though the executive management team did not initially set out to implement lean

manufacturing to create better relationships with employees on the manufacturing floor, strong evidence suggests this did occur. Employees expressed more positive feelings towards management. Many of the employees also expressed satisfaction with the lean manufacturing implementation, which may aid the organization as it continues to introduce lean practices. Finally, the executive management team must create an implementation plan and pre-described projects that includes all members of the organization in order to moving together towards a common goal. Management must be visibly connected to the project and participate in the lean manufacturing events [7].

In other side, the manager's behaviours and rewards should be focused on the management of a continuous series of short-term turning points, whilst the implementation of lean manufacturing that could create a firmer base for success by reducing costs and improving use of resources can be subject to continuous postponements "until better times". These companies would then be able to implement the concept of lean manufacturing successfully. But unfortunately, some other owner managers who may not have the lean management know-how and knows the least information about procedure of lean implementation disturb the flow of improvements. Consequently, because of the lack of specific procedure to lean implementation, managers should learn to think and see lean through their making decisions.

Strategies of implementation

Bhasin and Burcher (2006) agrees that there is general lean procedure consistent to any company, but each one should find their way through their conceptions from lean manufacturing [8]. Bicheno and Liker are strong in suggesting that a key component of lean thinking is to identify all the value adding time and reduce the non-value-added activities. Bicheno (2009), claims that in batch production about 98 percent of time activities is not value adding time; in the USA [9], Sheridan (2000), indicates that less than 2 per cent of all manufacturing jobs are in companies that are truly lean; that they have completed at least 80 percent of the conversion process [10]. Also, Womack et al. (2003) in their survey of automotive manufacturers, suggested that only 41 percent were assessed as having a high level of lean adoption. So, having a comprehensive knowledge of lean tools and being familiar with lean culture in adoption of right implementation and changes through incremental improvements and steeply projects by the reciprocal cooperation with workers until the completion of implementation is essential [11]. Sheridan (2000) proposes that lean implementation takes: "three years to become competent in applying such tools as set-up reduction, standard work or cell building and five years to introduce gradually a firm belief in all the tools" [10]. A key player is Liker (2004) who is clear in promoting a total approach; that lean cannot work with isolated tools [12]. Shingo (1989) also imply this policy. Securing the full benefits of lean requires the need to concentrate on the whole value chain suggest Command Mathaisel Allen, insist that for the Toyota production system to work effectively, it needs to be



adopted completely, not into pieces; Allen claims: “that lean management is a system approach”. Allen argue that lean is an entire business philosophy, as instigated by Ohno [13].

In equally, Karlson and Ahlstrom (1996), admit that a total philosophy is needed. Chase considers that getting lean: “also means that the business is examined in its entirety, including how orders are processed, the way materials are purchased, and the way manufacturing is done” [14]. Whilst Lathin and Mitchell (2001), subscribe to the total approach, the issue they stress is the need to combine the “socio-technical systems”; that all work organizations combine a technical, i.e. technology, and a social system, i.e. people and organizational structures [15]. Convis (2001), proposes that the TPS is an interlocking set of three underlying elements: the philosophical underpinnings, the managerial culture and the technical tools [16]. Pullin (2002), insists that to earn these benefits fully, it need to view lean not as an abstract philosophy but one which includes both concepts – a philosophy of management, and practices, tools or processes [17].

George Koenigsaecker, in Sheridan (2000), who has directed lean conversion initiatives in 18 manufacturing plants comments: “often people who attempt a lean conversion start with one of the tools, or a couple, and they push them through the organization. They then wonder why things are not flowing in the total value stream. The problem is that there are about a dozen key tools in lean manufacturing and you have to move them all ahead somewhat simultaneously”; he continues, “it is a long learning curve” [10]. Pullin (2002), insists that Land Rover, winners of the MX2002 “Manufacturing Excellence Award”, showed that not only had it adopted the lean philosophy but that it had adapted it to deal with certain local conditions [17].

Little published work, contest Jina et al (1995) exists that explicitly addresses the issue of whether lean methods are suitable and applicable in industrial sectors which are characterized by high variety, low volume and low repeatability of production [18]. Needy et al. (2000), suggest that the pioneering work within the automobile industry is misleading to draw correlations from as the conditions differ in many other industries [19]. Prabhu (1992), in his study of three different industries and non-Japanese companies located in the north-east of England suggests that lean is not restricted to only Japanese companies or mass production firms or larger organizations [20]. Allen (2000) insists that there is no “cookbook” to explain each step of the lean process and exactly how to apply the tools [21]. Lathin and Mitchell (2001) insist that quality improvements are only possible if companies implement comprehensive change management programs addressing “both the organizational and technological aspects of quality management” [15]. Bicheno (2009) argues lean needs to apply to every aspect of the value chain [9].

Karlson and Ahlstrom (1996) persist: “the important point to note, however, is that lean should be seen as a direction, rather than as a state to be reached after a certain time”. Moreover, all the determinants might not point in the right direction all the time; “there could be instances where they can send mixed signals” [14]. Emiliani (2006), documents how the Wiremold Company achieved outstanding success by using lean as a comprehensive management system, rather than a group of tools [22]. Henderson et al. (1999), explain how to employ techniques pioneered by Toyota including cultural issues should an organization wish to succeed in becoming a lean enterprise [23].

Formulating research hypothesis

Many enterprises have been introduced to lean manufacturing system and have made significant achievement. According to Pingyu and Yu (2010), a few of small medium enterprises have get



profit from the implementing lean manufacturing. SME play a significant role in the economic growth of developing countries, typically accounting for over 90% of business establishments and about half or more of output and export shares [24]. In yet another relevant study, the impact of LM is vividly depicted in steel industries. The authors, in this case, provided an in-depth analysis regarding lean implementation using a simulation approach to show the benefits observed in the steel industry. After applying LM, lead time was reduced at a significant percent- around ~70%- of total production time [25]. In a survey about the influence of LM on food, chemical and textile industries conducted by Koumanakos (2008), it was demonstrated that organizations without lean implementation had lower profits due to maintaining higher inventories. On the contrary, the improvement of financial performance was evidenced when the process industries of that type utilized and implemented LM. Lean manufacturing not only assists in enhancing manufacturing performance through removing different types of wastes in the process industry, but it also works as an impetus to compete efficiently in the present days, where quintessential priorities such as product quality, feedback capability and customer satisfaction are prevalent [26]. Perceived in the cases from previous research the hypothesis is formulated as follows:

1. After implementing 5S, efficiency will increase
2. After implementing 5S, workspace will increase.
3. After implementing 5S, equipment search time will be reduced.
4. After implementing 5S, laboratory working environment will be improved.
5. After implementing 5S, safety will be improved.

Methodology

The case method was first used in modern times in 1905 by Harvard Business School. This method examines a situation in narrative form by providing background, details, and a problem or problems. Then, the case is analysed and solutions are proposed as part of the learning process. It is a popular method of teaching in many business schools today. As Yin (2014) describes, a case study is a tool used to answer a question: what, why, how? In the context of this thesis, a case study is utilized to answer the question what: “What is the impact Lean Manufacturing has on small medium enterprise?” [27].

Interviews are useful to collect information based on research question of the study. There are different types of interviews, such as structured interviews, semi-structured interviews and unstructured interviews (Saunders et al., 2009). In this research a structured interview was conducted to the upper management which is the manager of the company. Structured interviews involve questionnaires based on a predetermined set of questions (Saunders et al., 2009). The purpose of this interview is to determine the level of Lean implementation of this company and are there any necessity to implement any of the lean philosophy [28].

The survey will be distributed one times for the relevant respondent before the 5S implementation and another one is after implementation of 5S. After the implementation there will be four consecutive times survey given to the same respondents, consists of one survey for each month. Survey is set up on a five-point Likert Scale to measure satisfactory of the respondent. The scale ranges from 1 to 5 where 1= Unsatisfactory, 2= Poor, 3=Satisfactory, 4=Good, 5=Excellent. The result of the all surveys will be analyses and compare after the 5S project is executed. The survey is basically focus on five areas which includes the evaluation of performance, workspace, equipment search time, working environment and work safety.



The process of making a stainless table undergo three process which include cutting, folding and assembly process. Each of the process duration were recorded every week and the observe time, OT represent the average time taken in a month. Based on the book which was written by Elizabeth (1998), the formulation for normal time, NT it represents the time which the experienced employee and freshmen were taken in consideration to estimate of time required which will probably be less than what can initially be achieved. Next is to obtain the standard time, ST for the whole process in making the stainless-steel table. A 10% of allowance factor, AF were considered to obtain the standard time, ST. AF represent the personal needs time which includes breaks, delays (equipment downtime), and fatigue [29]. The formula is given as follows:

$$\text{Observe time, } OT = \frac{1}{n} \sum_{i=1}^n x_i \text{ -----(Eq.1)}$$

$$\text{Normal time, } NT = OT \times PR \text{ -----(Eq.2)}$$

$$\text{Standard time, } ST = \left[\frac{1}{1 - AF} \right] \sum_{i=1}^n NT \text{ -----(Eq.3)}$$

Data obtained based on the response given will be analysed and discussed. This part is crucial to provide a general outlook on how the respondents responded to the questions given. Each question addressed in the survey will be analysed and presented in the form of standard chart graphical expressions by using Microsoft Excel.

Results

The result will be divided into two sections which include the employee’s performances data and the 5S survey data over the 5 months of this project.

Employee’s performances

The employees were observed over the 5 months to obtain their performances in the process of making the stainless-steel table as mentioned in methodology section. The employee’s normal time (NT) performances is shown Table 1.

Table 1: Employee’s normal time (NT) performance

Element	Before 5S	1st Month of 5S	2nd Month of 5S	3rd Month of 5S	4th Month of 5S
	NT, (min)	NT, (min)	NT, (min)	NT, (min)	NT, (min)
Cutting Process	127.25	119.75	119	117.25	114
Folding Process	154.75	150.75	147	147.25	146
Assembly Process	258.83	238.88	233.1	232.31	231.53



Standard time, ST of the whole process in making the stainless-steel table were recorded and calculated by using Eq.3 that was mentioned in methodology section. The employee's standard time (ST) performances is shown in Table 2.

Table 2: Employee's standard time (NT) performance

	Before 5S	1st Month of 5S	2nd Month of 5S	3rd Month of 5S	4th Month of 5S
Standard Time, ST (min)	600.92	565.98	554.56	552.01	546.14

5S survey

The survey held in two-way surveys which is one before implementing 5S and another one is after the implementation of 5S. The respondents were randomly handpicked from different positions within the company and the company's client. The survey is basically focus on five areas which includes the evaluation of productivity, workspace, equipment search time, working environment and work safety.

The first survey was kept before implementing 5S into the company. In all surveys thirty respondents were asked to answer the survey. For the five surveys over the 5 months, the response rate was 100%. There were ten questions in the survey and the rating scale was from one to five, one being unsatisfactory and five being excellent. The result for the first survey is shown in Figure 2, for the green bar represents the total number of respondents and the other colours represent the respondents' answers, while the dark blue on the right side represent the average score for the particular question.

SURVEY RESPONDENT BEFORE 5S IMPLEMENTATION

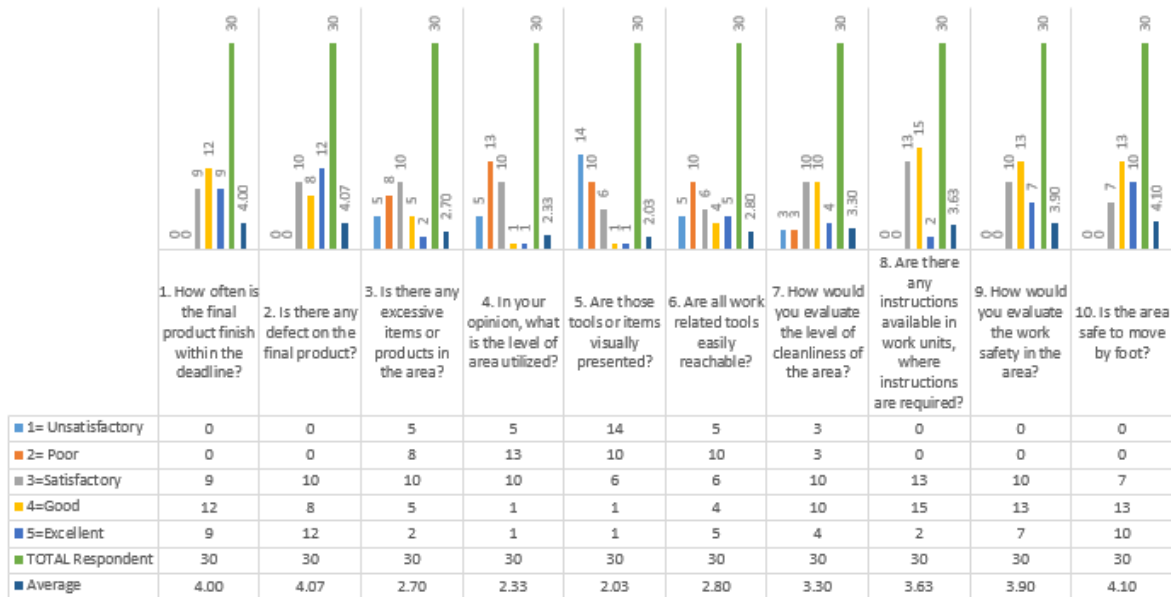


Figure 2: Result of survey respondent before 5S Implementation

The employees seem to be satisfied with Question 10 the overall safety of the area move by foot, as it scores on average a 4.10. On the other hand, respondents consider that question number five the tools and items were not visually presented as they were supposed, tools and items visibility were very low, since the score is as low as 2.03 on average. The area of utilization is the most crucial thing on every industry in order to increase their productivity. In the first survey, for Question 4 the level of area utilized scored is as low as 2.33 on average, which is not acceptable, as these utilized areas will gives the employee a comfortable workspace. The respondents consider for Question 3 that there are somewhat too much excessive items and products in the area, as the score for this is as low as 2.70, this might also reflect to the visibility of the tools and items. For Question 6 are all work related tool reachable scores on average 2.80, which still leaves room for improvement.

All respondents seem to be somewhat satisfied with Question 2 which related to the quality of product as they consider to be good. This question on average scores as high as 4.07 on average, followed with an average of 4.00 on question number one which considered to be satisfied which related to the product finish on time. The main reason for delay on finishing product were usually due to insufficient of raw material as the company doesn't have any spare storage for the raw material, for that reason, product that were requested by customer were not be able to run for process of making. For Question 8 which related to the instruction availability in the work station scored on average of 3.63, it seems that there's still a lot of instruction needed to be provided by the company all over the work place. The next question is Question 9 which related to the work safety. It seems that there were still many rooms of improvement in the safety area scored on average of 3.90. The last one is the question number seven which the survey is about the cleanliness

of the area, it seems this area could also be improved, as the question scores just above the average of 3.30.

Figure 3, Figure 4, Figure 5 and Figure 6 shows the results of the respondents after implementing 5S which respective month of 1, 2, 3 and 4. These surveys were kept to the same respondents, to get as accurate results as possible. Like in the first survey which was before the 5S implementation, also in the followed surveys thirty respondents, were asked to answer the survey and all respondents answered the survey. This means that the overall response rate for all surveys reached 100%.

SURVEY RESPONDENT AFTER 1 MONTH OF 5S IMPLEMENTATION

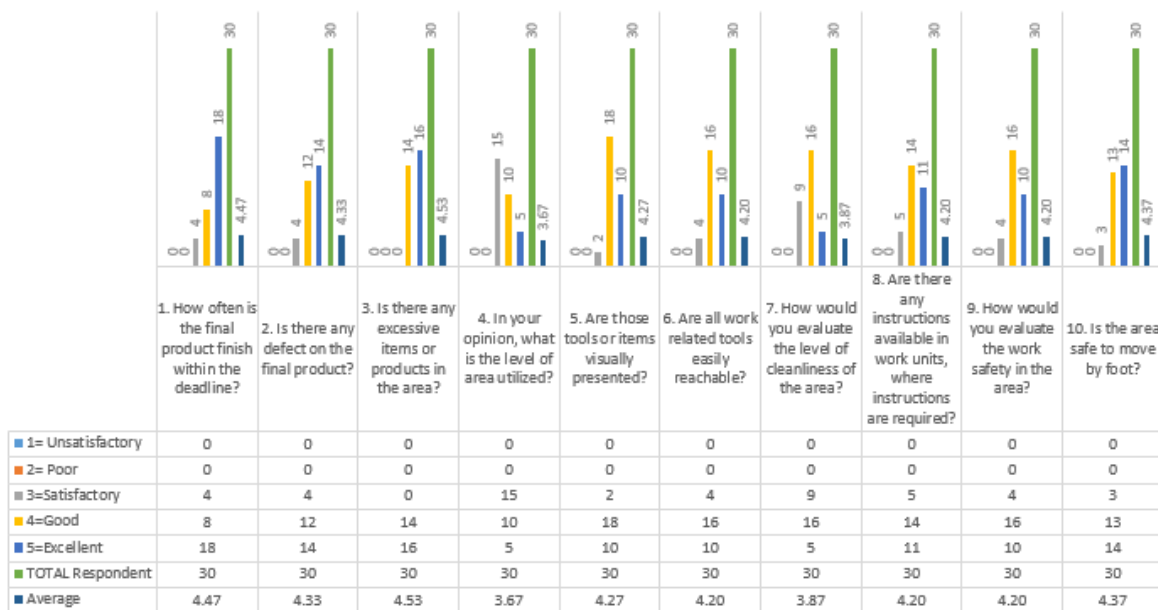


Figure 3: Result of survey respondent after one month of 5S Implementation

SURVEY RESPONDENT AFTER 2 MONTHS OF 5S IMPLEMENTATION

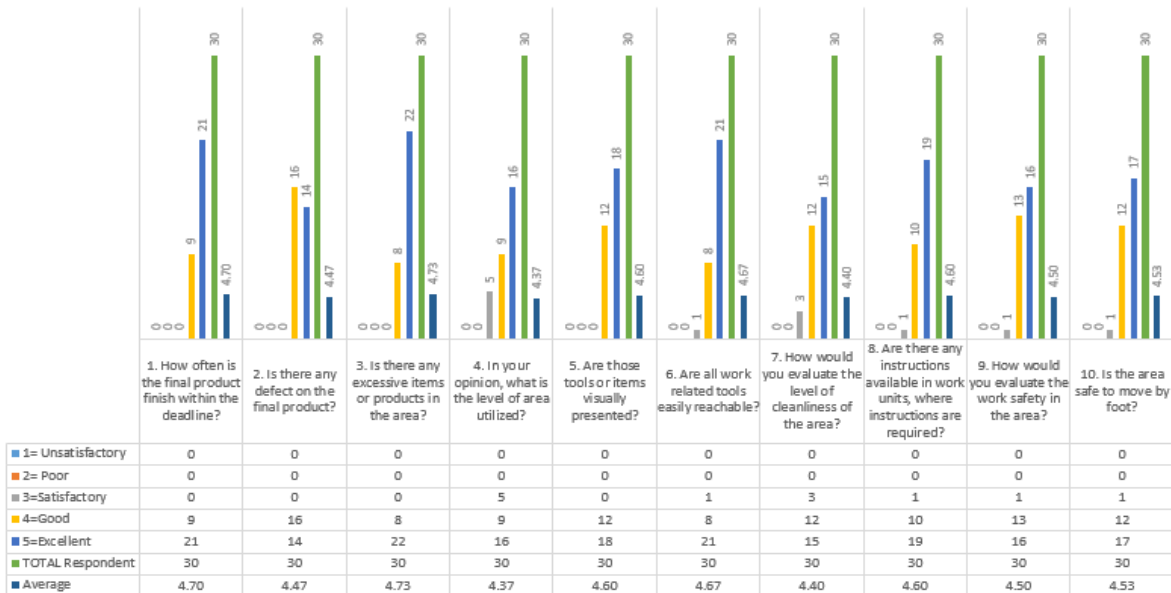


Figure 4: Result of survey respondent after two months of 5S Implementation

SURVEY RESPONDENT AFTER 3 MONTHS OF 5S IMPLEMENTATION

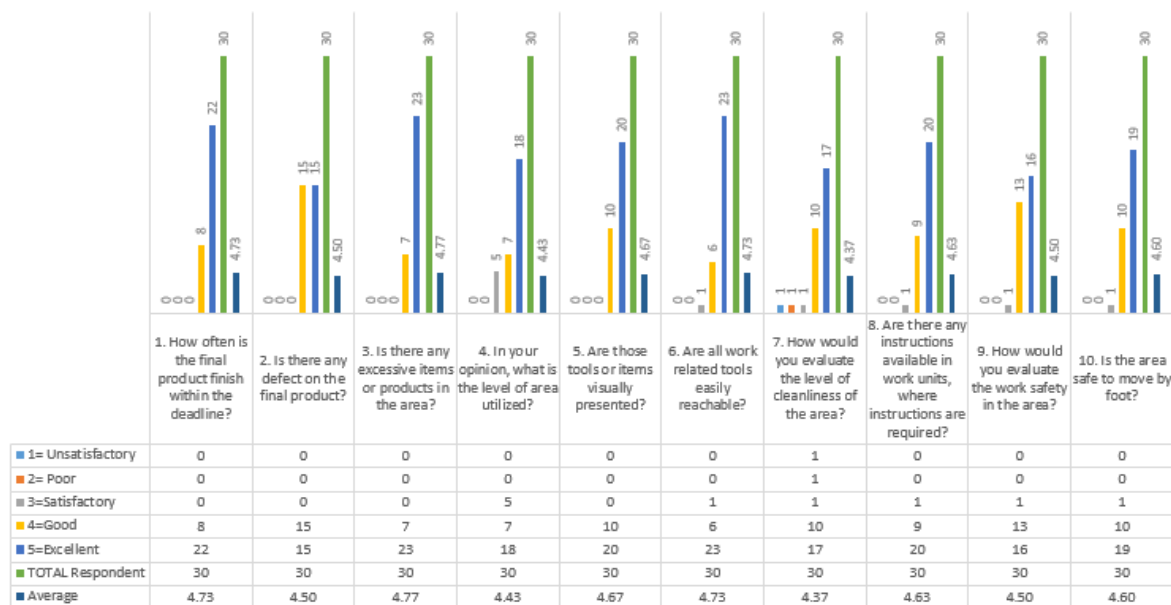


Figure 5: Result of survey respondent after three months of 5S Implementation

SURVEY RESPONDENT AFTER 4 MONTHS OF 5S IMPLEMENTATION

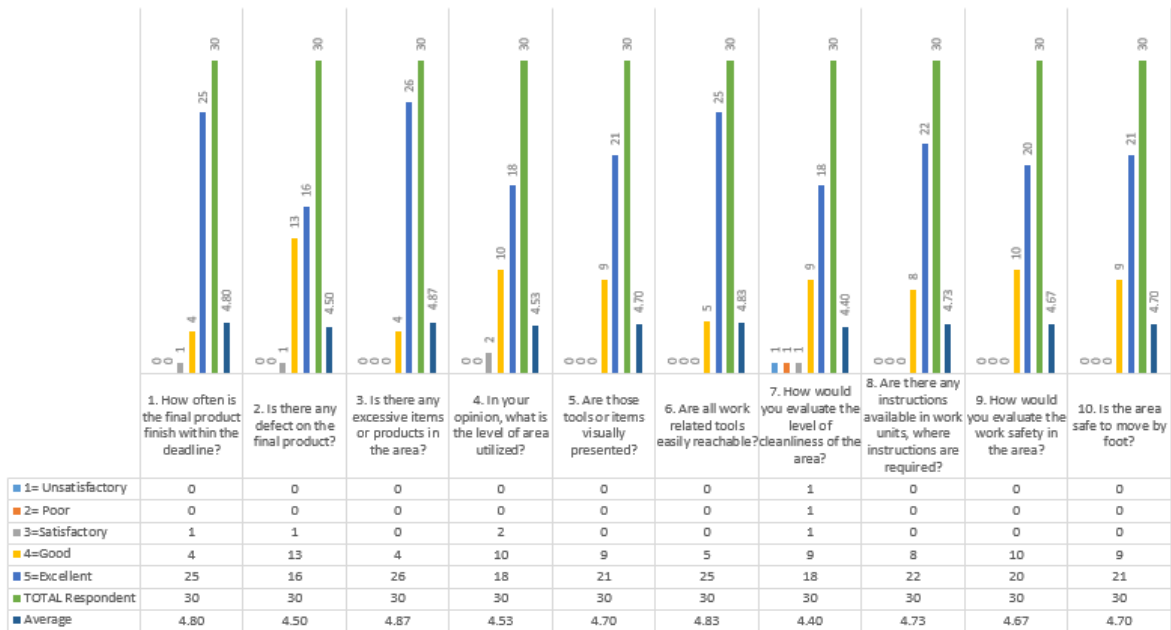


Figure 6: Result of survey respondent after four months of 5S Implementation

Discussion

The survey is basically focus on five areas which includes the evaluation of productivity, workspace, equipment search time, working environment and work safety.

Evaluation of productivity

The efficiency will be evaluated in two ways, one is through observation and the second one is through the survey respondent. Based on Figure 7, it seems that the assembly process's normal time has a significant change from 258.83 minutes to 231.53 minutes which has 27.3 minutes faster in comparison over the five months. The significant change in assembly process were probably due to the improvement in the tools and items that were well organized. Besides, the changed that were made in the area utilization were also partially contributed to this improvement of time change due to more workspace for the employee. While for folding process and assembly process has 8.75 minutes and 13.25 minutes of change over the five months. It may seem that these two processes were only slightly improved, it may due to these processes were mostly being done by operating machine.

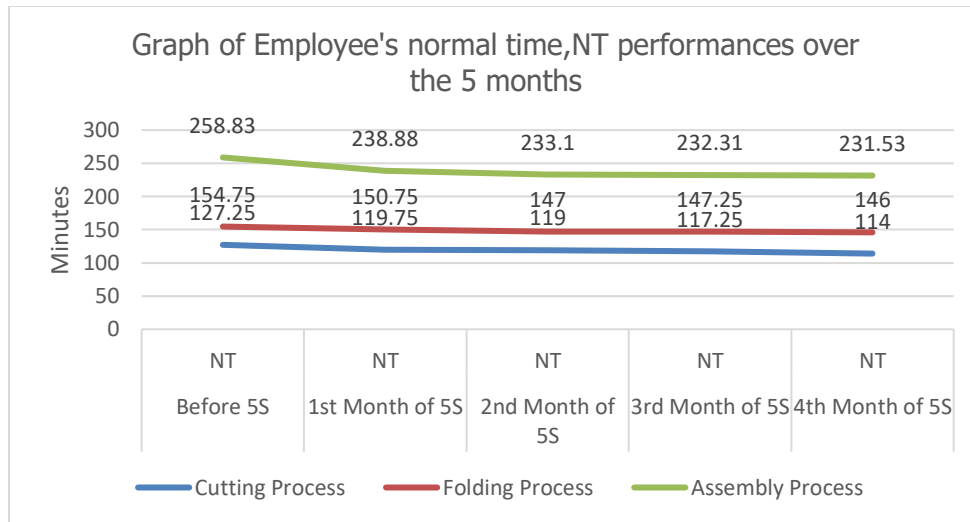


Figure 7: Graph of employee's normal time (NT) performances over five months

In Figure 8, a standard time of the whole stainless-steel table making process were analysis over the five months from before the 5S implementation until the following months. The graph shows a major change from 600.92 minutes to 546.14 minutes which has a total of 54.78 minutes of change. The improvement in this area has increase the satisfaction towards the customer and employee throughout the survey that has been given after the 5S implementation.

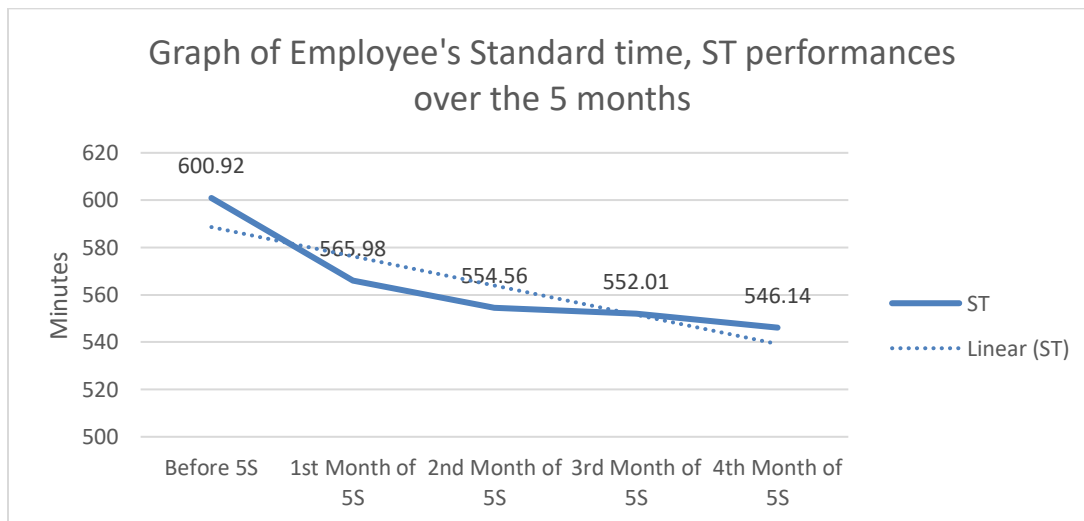


Figure 8: Graph of employee's standard time (ST) performances over five months

Figure 9 shows the graph analysis for Question 1 which considered to be satisfied scored at an average of 4.00 for the first survey. After the 5S implementation, the score increased by 0.80. This may due to the spare storage were utilized by the company after the 5S implementation.

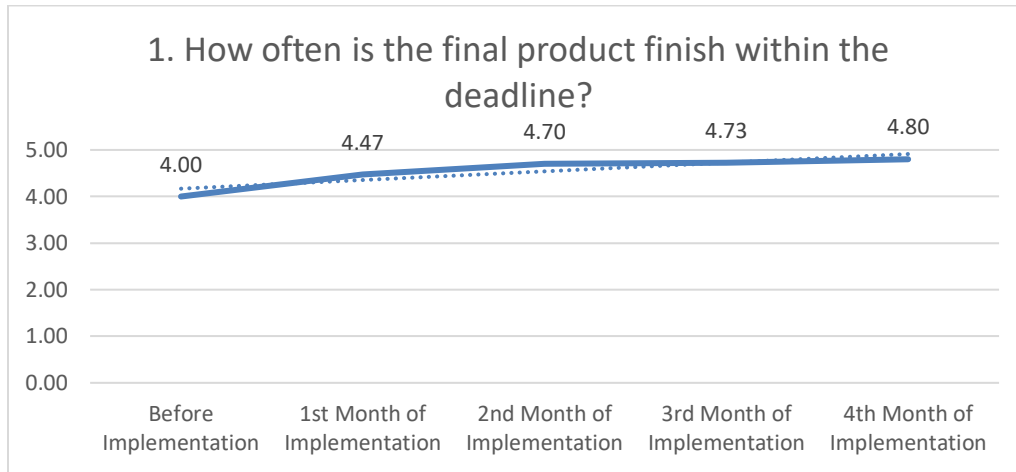


Figure 9: Result comparison over five months for Question 1

Figure 10 shows the graph analysis for Question 2 which related to the quality of product. It has shown in the graph that the product’s quality also has improved from time to time after the 5S implementation. The score has 0.43 of score in overall improvement. The main reason in this improvement may due to the improvement in workspace. The greater the workspace, it will give more comfortable to the employee and less fatigue. Thus, product quality will increase.

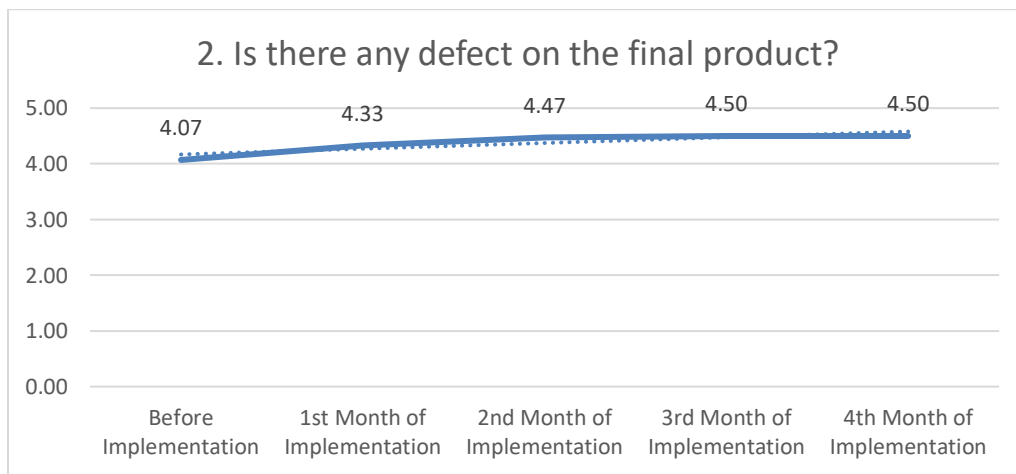


Figure 10: Result comparison over five months for Question 2

Evaluation of workspace

Figure 11 shows the graph analysis for Question 3 that there are somewhat too much excessive items and products in the area, as the score for this is as low as 2.70 at the first survey. After the 5S implementation, excessive items and products that were usually surrounded the workspace were

well organized. With this adjustment more workspace available. It has a significant change of score from 2.70 to 4.53 at first month of implementation which has 1.83 of improvement in score. By the fourth month of implementation it has another 0.34 of improvement which gives a total of 2.17 improvement in score.

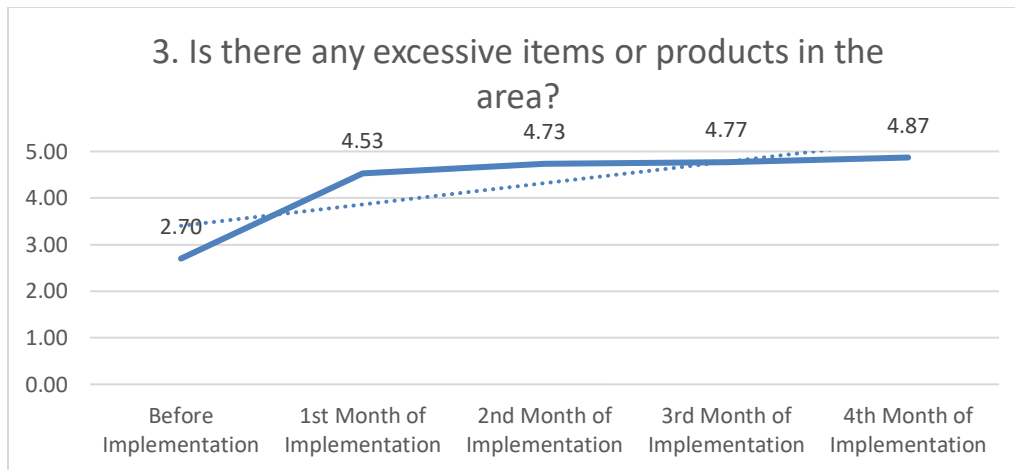


Figure 11: Result comparison over five months for Question 3

Figure 12 shows the graph analysis for Question 4 the level of area utilized, and this question scored as low as 2.33 on average, which is not acceptable, as these utilized areas will gives the employee a comfortable workspace. After the implementation of 5S many of the work space were utilized, and some of the area which were abandoned for long are now being utilized. Some of area are used as storage. After these adjustments, with 5S implementation the score increases from 2.33 to score of 4.53.

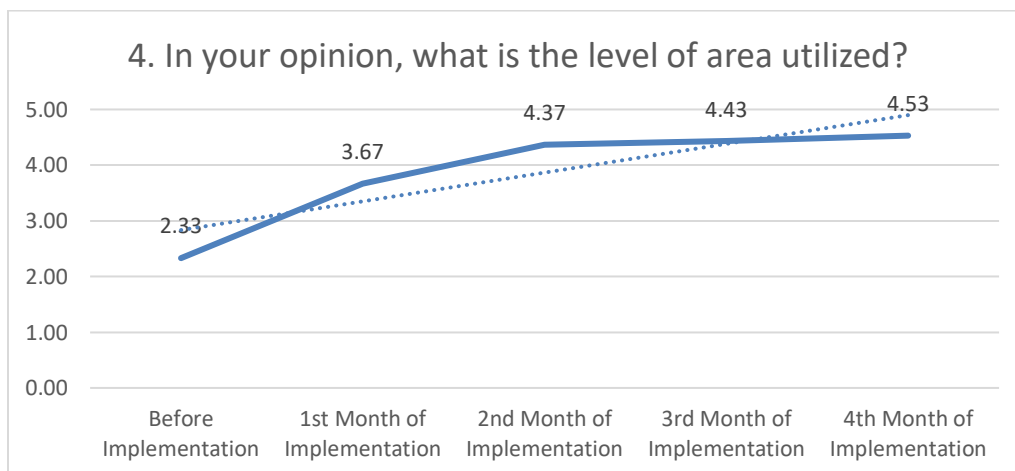


Figure 12: Result comparison over five months for Question 4

Evaluation of equipment search time

Figure 13 shows the graph analysis for Question 5 which asked if the tools and items were visually presented as they were supposed, and the score is as low as 2.03 on average before the 5S implementation. At the fourth months after the implementation of 5S, this is most notable improvement which has a total of 2.67 scores increments. Employees are satisfied with the well managed and organized tool and easy to find. This adjustment also contributed to improvement in efficiency and safety rather than just search time will be reduced.

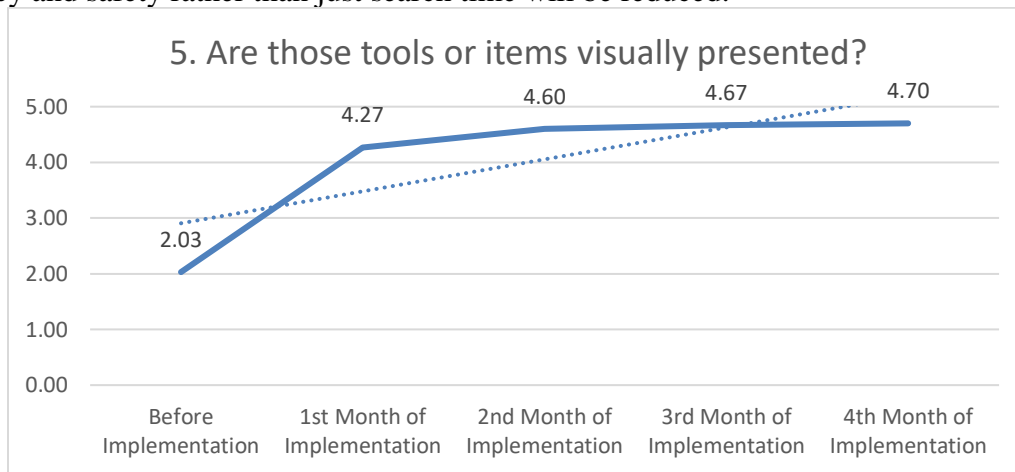


Figure 13: Result comparison over five months for Question 5

Figure 14 shows the graph analysis for Question 6 which are also related to Question 5. This question scores on average 2.80 before the 5S implementation. This question also shows a major increment of score which has score of 2.03 improvement. Employee easily acquire the work-related tools after the adjustment on the tool placement. This proven that implementation of 5S reduce the equipment search time.

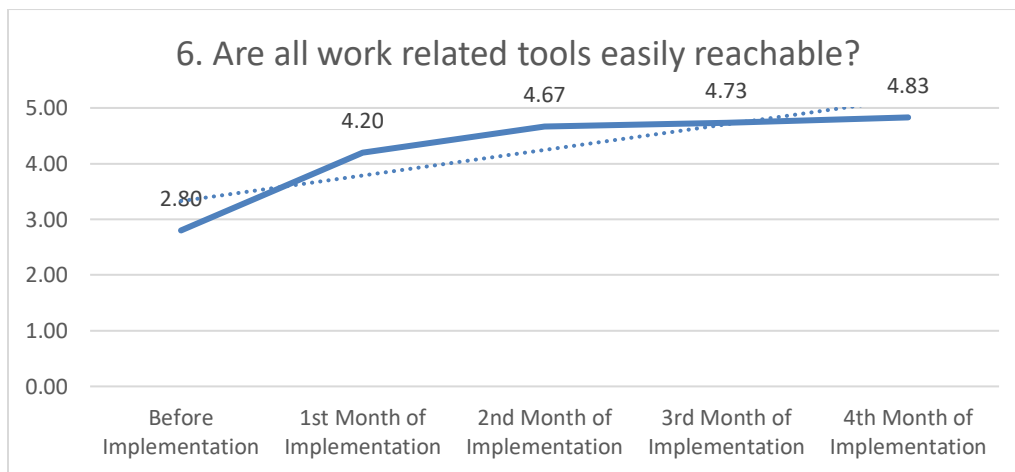


Figure 14: Result comparison over five months for Question 6

Evaluation of laboratory working environment

Figure 15 shows the graph analysis for the Question 7 which the survey is about the cleanliness of the area, it seems this area could also be improved, as the question scores just above the average of 3.30 before the 5S implementation. The cleanliness of company may seem to be gradually increase after the 5S implementation and stay fluctuate from second month to fourth month. The cleanliness of the company will require the cooperation from every of the employees in order to sustain this process. The work place should be as clean as it was after using it. The reason that the score remains fluctuate might be due disobedience from some of the employee in the company. However, it still has a total of 1.10 increase in score after 5S implementation at fourth month in compare with before the 5S implementation.

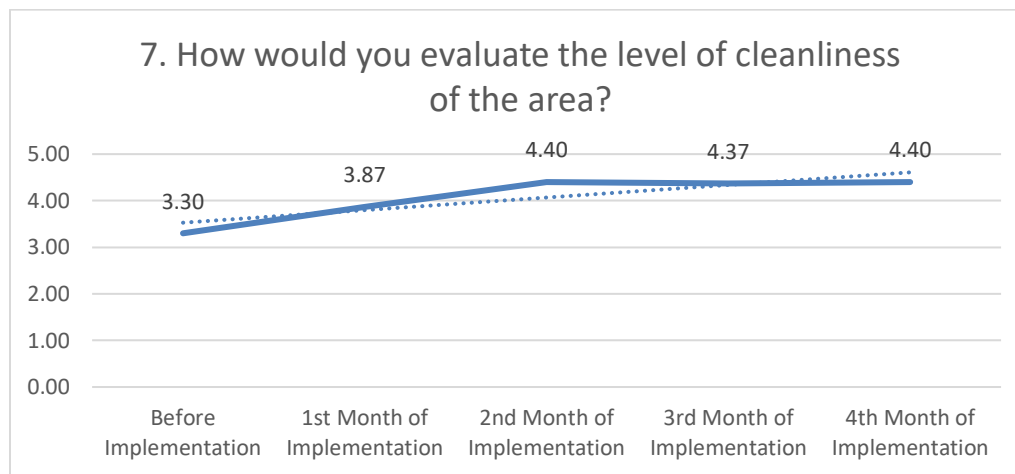


Figure 15: Result comparison over five months for Question 7

Figure 16 shows the graph analysis for the Question 8 which related to the instruction availability in the work station scored on average of 3.63, it seems that there's still a lot of instruction needed to be provided by the company all over the work place at the first survey. After the 5S implementation, it has shown that there is an outstanding improvement from score of 3.63 to 4.73 which has a 1.10 improvement of score. As there is more instruction in the work place, the employee will also be cautious of environment in the laboratory. This will also beneficial to the safety environment.

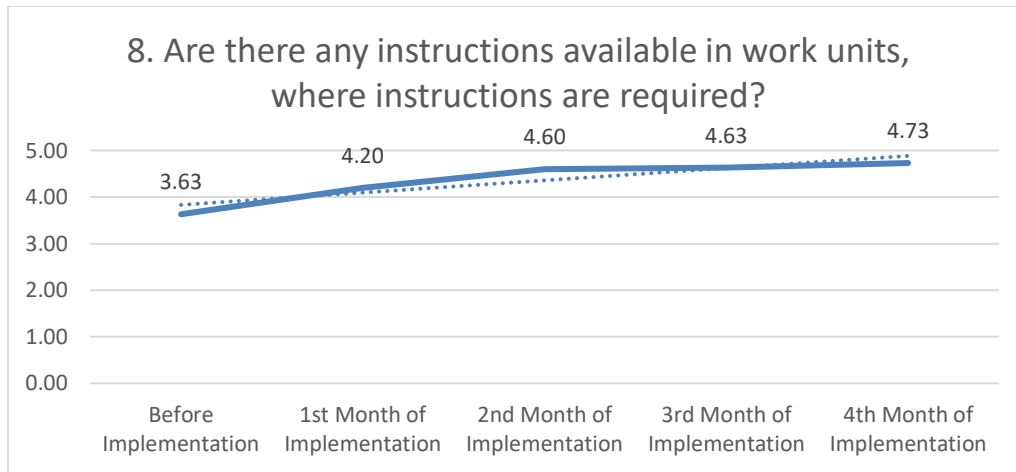


Figure 16: Result comparison over five months for Question 8

Evaluation of work safety

Figure 17 shows the graph analysis for Question 9 which related to the work safety. It seems that there were still many rooms of improvement in the safety area scored on average of 3.90 at first survey but improved to score of 4.67 which has 0.77 increases in the score at the fourth month of 5S implementation. Safety is linked to work management. As 5S is one of the management enhancement methodology, the application of 5S will greatly benefits the safety of work place.

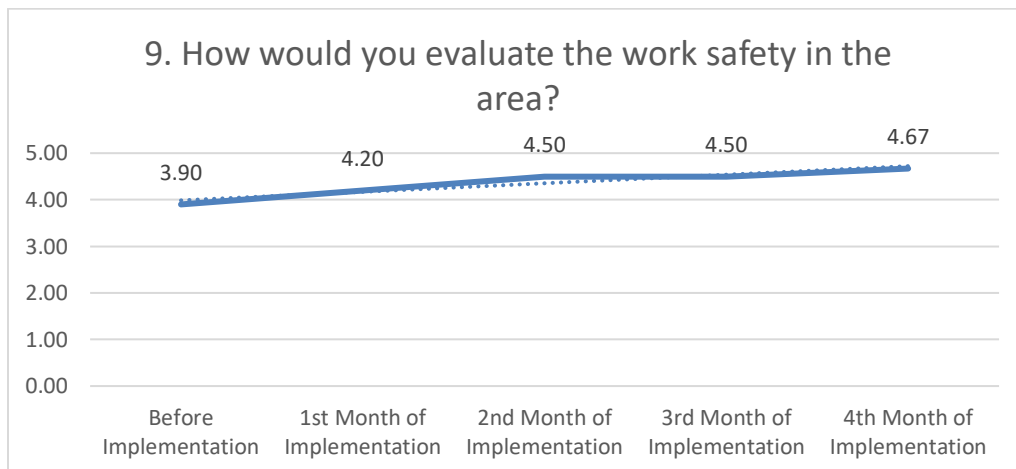


Figure 17: Result comparison over five months for Question 9

The employees seem to be satisfied with Question 10, the overall safety of the area move by foot, as it scores on average a 4.10 at the first survey nevertheless. Figure 18 shows that it has improved to score of 4.70 over the 5 months of 5S implementation which has a great improvement of 0.60 scores. This may have linked to question number three which the excessive product and items were well organized and due to this the excessive item on floor were removed for foot to move safely. It has proven that 5S implementation improves safety.

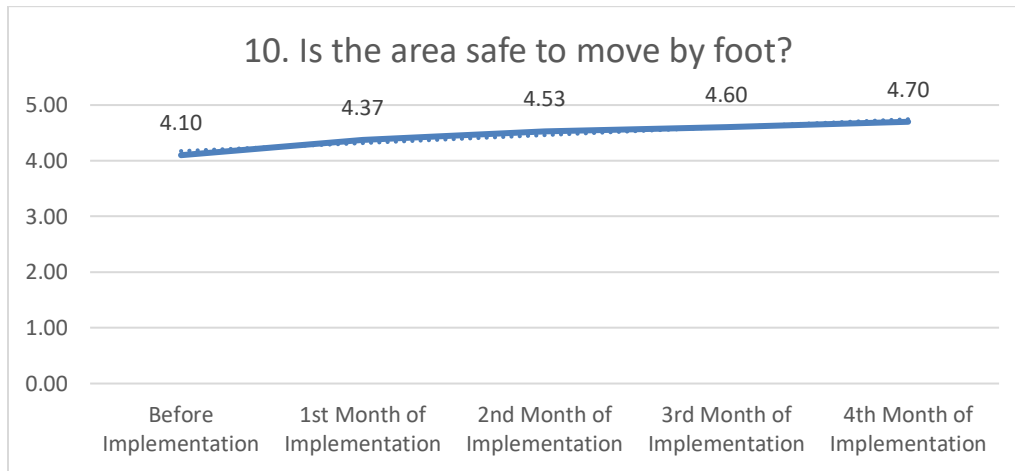


Figure 18: Result comparison over five months for Question 10

Conclusion

The project of this study reveals that lean implementation has seriously improved the company in many areas. Despite, the lean manufacturing usually only implemented by most of the large industry, but the project shows that lean implementation towards SME is additionally beneficial. The 5S system is a good starting point for all improvement efforts aiming to drive out waste from the manufacturing process and ultimately improving a company’s bottom line production by improving products, services and lowering costs.

Many manufacturing facilities have opted to follow the path towards a “5S” work-place organizational and housekeeping methodology as part Lean Manufacturing processes in order to achieve higher levels of quality through minimization of waste. On other hands, 5S methodology has found increase in productivity and hence profit levels.

During the 5S implementation, a lot of valuable and important observations were made and many of them were implement in order to have a complete 5S environment. The area, in which the implementation was taken into action are mostly of the issues were related in organizing and cleaning. For now, it seems that 5S has become a part of every employee’s daily working habits, but it is still too early to state this for sure, as there might be change in the future. Some employees and other staff members still, so to say, are somewhat against the idea of 5S, which is of course understandable. However, the possibility of ignoring the changes and going back to the way it was before, still appears.



The changes that 5S brought, according to the survey over the five months, was all positive. None of the areas reached the maximum total score, but the improvement was remarkable in each area. The survey was given only for thirty respondents, which of course does give a little thorough opinion of the company. The most remarkable change was related to tools visibility. This factor increased by 2.67 in comparison from the fourth months of 5S implementation with before the 5S were held, which proves that the respondents are satisfied with the tool placement. However, the least change was question 2 which was related to the evaluation of performance. This factor increased by 0.43, which might because product's quality is a factor that change over with skills and experiences of the employee. Now that the employees are getting more familiar with the concept of 5S, improvement ideas are more likely to raise. In addition, after the 5S implementation, the standard time in making one of the products has a total of 54.78 minutes of change. Thus, this will aid the company to produce one extra product for every eleven productions of this product in comparison with before the 5S implementation. Unfortunately, due to the time constraint in conducting this case study, only one product was observed and measured the change in duration of production time.

In short, it was found that after the 5S implementation, the evaluation in the five areas have increased which includes performance, workspace, equipment search time, working environment and work safety. However, some areas still need improvements, but that is what lean is about, continuous improvement. Continuous improvements have become especially important in the industrial field.

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RELATIONSHIP BETWEEN MOISTURE CONTENT AND DIELECTRIC VALUES OF CONCRETE USING GROUND PENETRATING RADAR METHOD

Nur Suria Ahmad¹
Roszilah Hamid²

¹Civil Engineering Program, Smart and Sustainable Township Research Centre, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

²Civil Engineering Program, Smart and Sustainable Township Research Centre, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia (email: rosizilah@ukm.edu.my)

Abstract: *The moisture content (MC) in concrete structures is an agent that may result in corrosion of steel reinforcement and further deterioration of concrete. The non-destructive technique (NDT) of the Ground Penetrating Radar (GPR) is a technique to assess concrete structures' condition. However, the propagation of GPR electromagnetic waves (EW) is strongly influenced by the MC of propagation medium. Hence, the objective of this study is to determine the effect of MC on EW velocity and dielectric value based on different MC of concrete and at various steel reinforcement diameters. Antenna frequency of 1.6 GHz is used based on the depth of the reinforcement which is less than 0.5 m. A concrete slab of 0.15 x 0.20 x 0.35 m³ was prepared using three different sizes of steel reinforcement of 12, 16, 20 (mm) at different depths of 25, 60 and 120 (mm). After 28 days wet cured, the sample is oven-dried to remove moisture. Next, the sample was immersed in water for 5 min, 10 min, 30 min, 60 min, per hour to 6 hours, from day 1-9 to obtain different MC. The effect of concrete MC on GPR EW can be seen through the hyperbola image, which begins to fade on the 3rd day of immersion, at MC of 2.31%. The dielectric values obtained are 10.11 for concrete that are immersed for more 9 days (MC 2.54%). The range of dielectric values obtained are within the range in ASTM D-6432, which is 5-10 for concrete. Finally, the percentage difference (%) of the diameter steel reinforcement obtained for relative MC is 0.3% for size 12 mm, 28.56 for size 16 mm and -7.7% for size 20 mm. The percentage difference (%) increases when MC increases. Relationship between %MC within the value obtained and dielectric value is proposed.*

Keywords: Moisture Content, Ground Penetrating Radar, Dielectric Value, Size of Rebar, Rebar Depth

Introduction

Concrete protection plays an important role in protecting structural elements, particularly reinforcement. Concrete cover is a barrier to moisture, carbon dioxide and chloride which can cause corrosion of steel reinforcement. Therefore, the characterization of concrete cover is important to the resistance of concrete structures (Agred et al. 2018). A non-destructive technique (NDT) of Ground Penetrating Radar (GPR) shows its effectiveness in evaluating concrete structures. According to Hasan & Yazdani (2014) GPR was initially used in geophysics to

determine the nature of the land and then applied in the civil engineering sector. GPR is used to assess concrete or masonry structures in determining slab thickness or reinforcement location, as well as to determine moisture content (MC) in concrete. Most usage of GPR are related to rebar detection and mapping. The layout, MC and voids in the structure can also be assessed using GPR (Lai et al. 2017). The GPR electromagnetic wave velocity is associated with the content and MC in a substance, such as soil and rock.

The relationship between GPR electromagnetic wave velocity and MC had been reported by Sbartai et al. (2006) & Senin, & Hamid (2016) . The wave velocity changes are indicated by direct wave amplitude and reflected wave amplitude. Direct waves are waves that are from the surface reflection of the concrete while the reflection wave is a reflection from the metal object. Figure 1 shows an inversely proportional relationship between the electromagnetic wave velocity and MC between 0 to 16 %. The electromagnetic wave velocity decreases when MC increases. Rodriguez-Abad et al. (2014) has also shown the effect of MC on electromagnetic wave velocity. The two way-travel times of the reflected wave increased when the samples were immersed in the water. The wave amplitude peaks of the reflected decreased when the sample were immersed into water. The shift in the two-way travel time of the reflected wave recorded when the sample was immersed into water and when the sample was dry (Figure 2). This causes the EM wave propagation velocity to decrease, and thus resulting in the increasing of dielectric value.

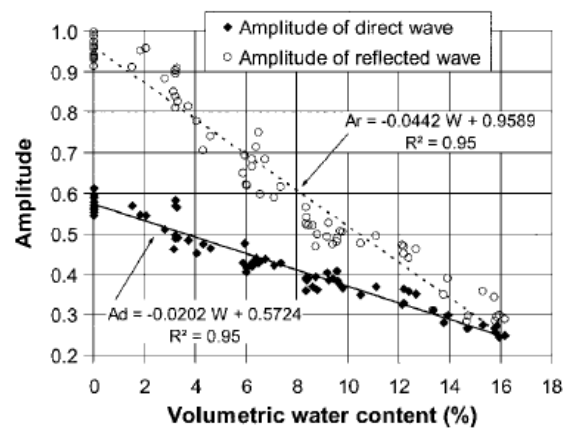


Figure 1: Relationship between EM wave velocity and moisture content (%).
Source: Sbartai et al. (2014)

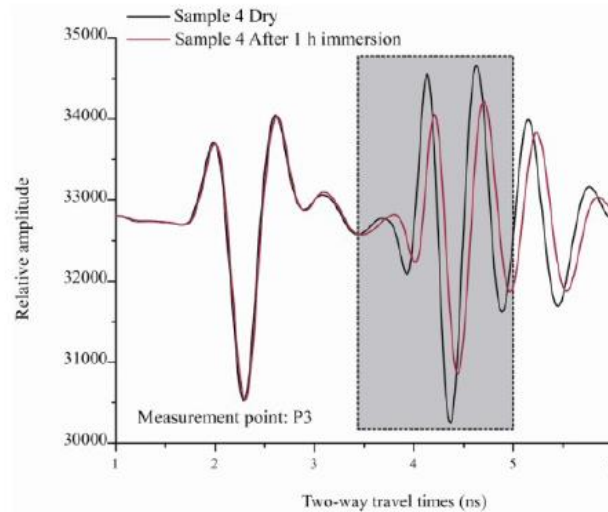


Figure 2: Signals recorded for sample 4 when it was dry and after 1h immersion in water.

Source: Rodriguez-Abad et al. (2014)

According to Kaplanvural et al. (2018), the decrease in EM wave velocity due to MC had caused the dielectric value to increase. Relative dielectric permittivity of the media can be estimated from the radargrams using the hyperbola fitting. By fitting the hyperbolas to the first reflections from the rebar, the velocity of the concrete can be calculated which gives information about the water content in a concrete (Figure 3). The dielectric value increase when there is a presence of moisture content in the concrete. Leucci (2012) shows the relationship between the dielectric value and MC between 4 to 16 %. Observing the plot in Figure 4, it can be seen that it is a polynomial relationship between dielectric value and moisture content suggesting a strong relationship between both.

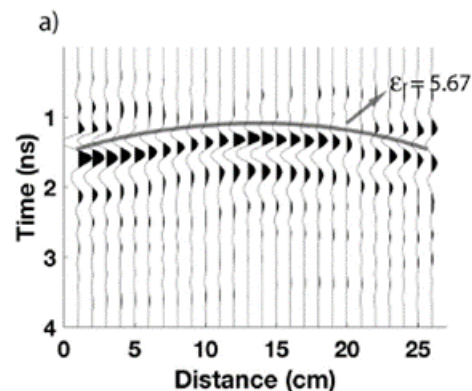


Figure 3: The radargrams of measurements at 3rd day

Source: Kaplanvural et al. (2018)

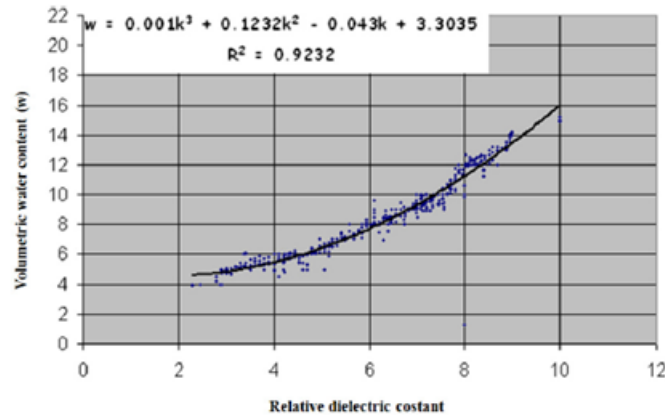


Figure 4: Volumetric water content (w) as a function relative to dielectric constant (k)
Source: Leucci (2012)

According to Dinh et al. (2016), amplitude reduction of the GPR radar wave changes based on wave propagation in a medium. The wave amplitude will decrease when the medium is deep and the distance travel increases. The reflection strength (amplitude) of a steel reinforcement increases with the size and decreases with depth or presence of moisture content. The size of steel reinforcement can be estimated from reflection strength on a comparative basis, but cannot be accurately measured (Lakshmi et al. 2016). For concrete structures that have two layers of steel reinforcement, the visibility of the second layer depends on the spacing in the first layer and on the amount of attenuation and scattering in the concrete. Wave attenuation occurs when there is a reduction in signal wave strength during transmission and reduces the penetration of electromagnetic waves. Another factor that causes wave attenuation is high conductivity material. Many studies have been conducted in determining the size of steel reinforcement, but it still have many limitations (Hasan & Yadzani, 2014). For example, study by Utsi & Utsi (2004) shows that there is a problem in interpreting the images when the distance between the steel reinforcement close to 200 mm.

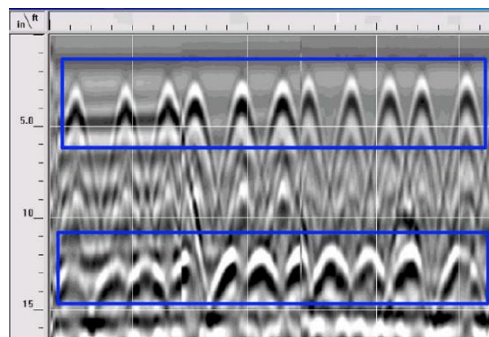


Figure 5: Two closely spaced layer of rebar
Source: Geophysical Survey System Inc (GSSI)

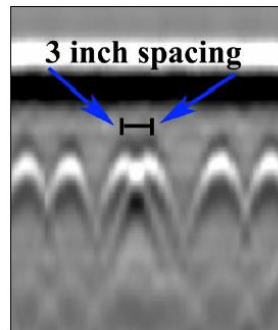


Figure 6: Two cables 3 inch apart
Source: Geophysical Survey System Inc (GSSI)

Figure 5 and 6 shows a steel reinforcement layer that has a distance of 25 cm vertically. The steel reinforcement layer at the top is clear. The second layer of steel reinforcement becomes more difficult to see as most of the electromagnetic waves transmitted are reflected from the top layer and does not penetrate the second layer completely. Furthermore, in order to obtain separate hyperbola reflection, the lateral spacing of the reinforcement must be at least 3 inch or 7.5 cm (GSSI) (Figure 6).

Basic concept of GPR

A GPR system emits an electromagnetic wave into the ground through transmitting antenna and receive the response. Figure 7 shows the principles of GPR system. If there is a change in electric properties in the ground or if there is an anomaly that has different electric properties than the surrounding media, a part of the electromagnetic wave is reflected back to the receiver. The system scans the ground to collect the data at various locations.

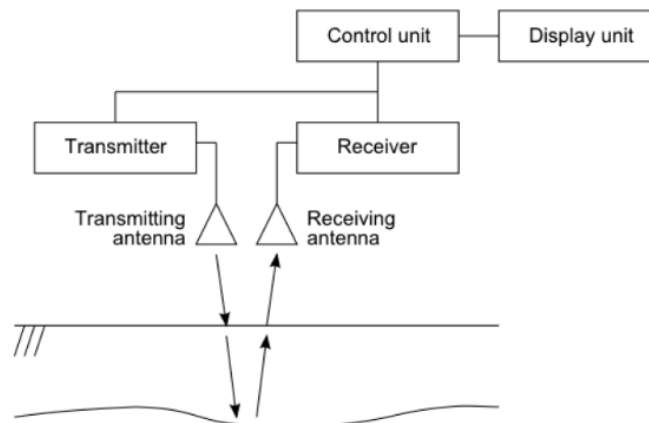


Figure 7: Basic principles of GPR system (ASTM D6432-99 (2005)).



Dielectric value depends on density, texture, mineral content, temperature and water content. However, the dielectric value of a material is highly influenced by the amount of water content. The dielectric constant affects the propagation of GPR electromagnetic wave velocity in terms of speed and reflection. If the dielectric constant is higher, the reflection of electromagnetic wave signal is also increasingly difficult to obtain. Therefore, water plays an important role in determining the dielectric in a substance (Takashi et al. 2012).

Dielectric Value

According to ASTM D432-11, which is a guideline use of the GPR method, if the dielectric value, ϵ_r is unknown, the electromagnetic wave velocity can be estimated using equations:

$$v = \frac{2D}{t} \tag{1}$$

where,

v = velocity of electromagnetic waves, D = the depth of the object and t = time of two-way waves and the dielectric value, ϵ_r can be obtained using equation:

$$v = \frac{c}{\sqrt{\epsilon_r}} \tag{2}$$

where,

c = light speed, 3×10^8 m/s and ϵ_r = dielectric value

In this research, the effect of MC on the determination of steel reinforcement depth in concrete and their determination of diameter sizes are studied. The MC affects the value of dielectric constant of the concrete slab. Different sizes of reinforcement are placed at different depth in grade 20 MPa slab. The slab is wet cured for 28 days and later dried in oven until constant weight is achieved (marked as 0% MC). Next, to obtain the relative MC, the slab is immersed in water and GPR testing to determine the depth and diameter of steel reinforcement were done at various periods to obtain different % MC. The slab was also weighted to determine the percentage increase of moisture content.

Experimental Design

Sample preparation

The sample is Ordinary Portland Cement (OPC) concrete with water/cement ratio of 0.57. The compressive strength of the concrete is 20 MPa. The mix design proportions of the sample are summarized in Table 2.

Table 1: Type of medium and dielectric value

Cements kg/m ³	Sand kg/m ³	Aggregates kg/m ³	Water kg/m ³	W/C ratio
333.3	907.6	943.1	216.3	0.57

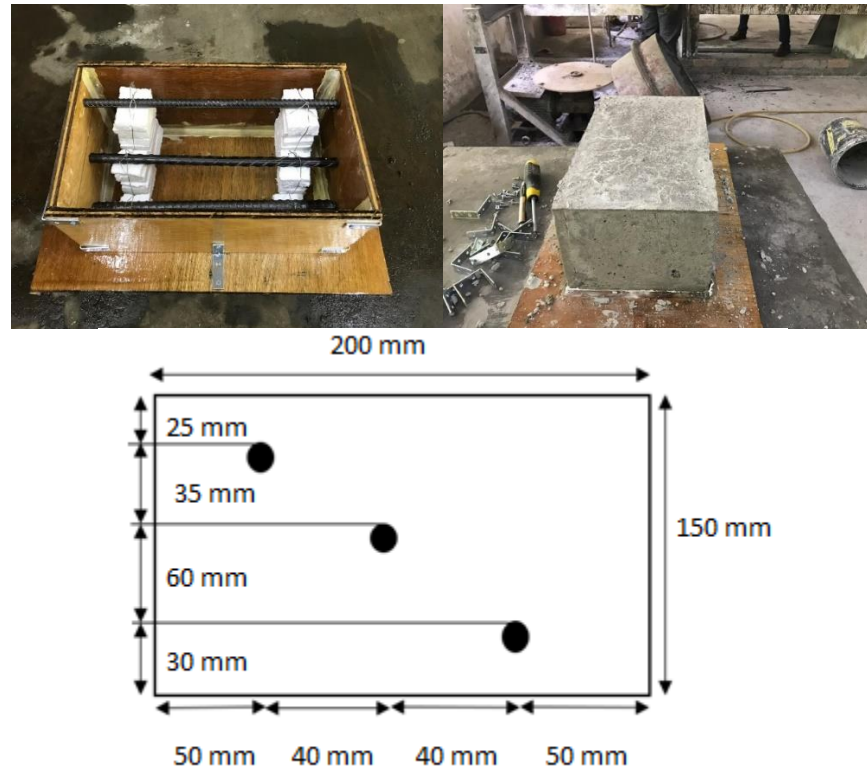


Figure 8: Concrete samples preparation and schematic diagram of the steel reinforcement location

The dimensions of the reinforced slab are $0.15 \times 0.20 \times 0.35 \text{ m}^3$ with three different sizes of reinforcement bar which are 12 mm, 16 mm and 20 mm. The steel reinforcement are located at different depth of 25 cm, 60 cm and 120 cm respectively (Figure 8). After casting, the concrete slab was cured for 28 days. The absorption rate of concrete was measured according to ASTM C1585-04. Before the immersion process started, the samples were placed in an oven at a temperature $50 \pm 2^\circ \text{C}$ for 3 days. Then, the samples were placed inside a sealable container for 15 days. Storage in the sealed container for at least 15 days results in equilibration of the moisture distribution. The mass of the concrete was 22.40 kg for relative moisture content 0 %. The samples are then immersed in the water with different period of time stated in Table 2 (based on ASTM C1585-04).

Testing

GPR measurement were carried out using SIR 3000 system with 1.6 GHz antenna, developed by Geophysical Survey Systems Inc. (GSSI). GSSI cart was used to collect the data in distance mode, sampling rate of 256 sample per trace, based on automatic configuration in the system.



Table 2: Times and tolerances for the measurement schedule

Time	5 min	10 min	30 min	60 min	Every hour up to 6 h	Once a day up to 3 days	Day 4 to 7 (3 readings)	Day 7 to 9 (1 reading)
Tolerance	10 s	2 min	2 min	2 min	5 min	2 h	2 h	2 h

Results and Discussion

The GPR readings were taken for the first 9 days, up until the amount of MC was found to be constant, that is when there was no further increase in the mass of the slab. Table 3 show the percentage of moisture content obtained based for different period of time.

Table 3: Example (TNR, 10, single spacing, bold, centre)

Days	Time (s)	Mass (kg)	Δ Mass (kg)	Relative MC (%)
-	0	22.40	0	0
-	300	22.64	0.24	1.06
-	600	22.70	0.30	1.32
-	1800	22.73	0.33	1.45
-	3600	22.76	0.36	1.58
-	7200	22.78	0.38	1.67
-	10800	22.80	0.40	1.75
-	14400	22.81	0.41	1.80
-	180000	22.82	0.42	1.84
-	21600	22.84	0.44	1.93
2	193200	22.92	0.52	2.27
3	268500	22.93	0.53	2.31
5	432000	22.94	0.54	2.35
6	527580	22.95	0.55	2.45
7	622200	22.96	0.56	2.50
9	777600	22.97	0.57	2.54
10	864000	22.97	0.57	2.54
11	950400	22.97	0.57	2.54
12	1037000	22.97	0.57	2.54

Effect of moisture content on hyperbola reflection

The raw data obtained from GPR are filtered and processed (zero-time correction, background removal and migration) using *Radan 7*. Zero-time correction is done to remove the delay time from the first reflection to correct the effect of transmitter and receiver antenna distance and possible variation of direct wave arrival time. This process also filters and removes the airspace that is located on the surface of the medium at the top. Lastly, migration process is aimed at highlighting the hyperbola curved point and hence knowing the travel time of two-way electromagnetic waves and the velocity of the electromagnetic wave (GSSI).

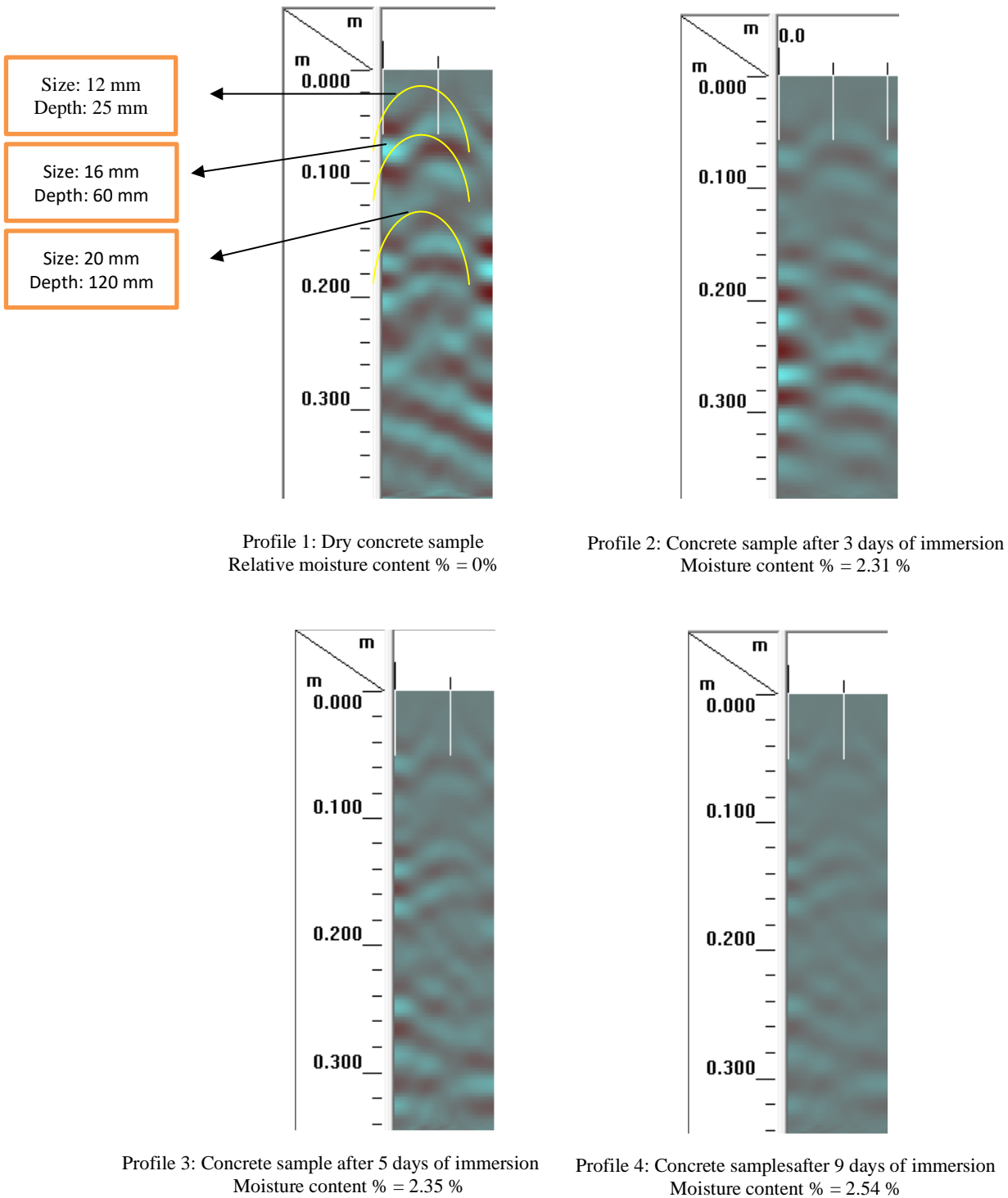


Figure 9: Profile of hyperbola reflection



The resulting hyperbola is in the same position, parallel, whereas the lateral spacing for each steel reinforcement is 4 cm. This is because based on GSSI, in order to obtain separate hyperbola, the spacing between the steel reinforcement should have at least 7.5 cm (Figure 6). Therefore, the resulting position is inaccurate. However, the depth obtained is within the correct range which is 25, 60 and 120 mm based on Figure 9.

Based on Figure 9, the effect of concrete MC on GPR can be seen through the hyperbola reflection, which is fading due to the increase of MC in concrete. Profile 1, which is at relative MC 0%, shows a relatively clear hyperbola to determine the depth of steel reinforcement. The hyperbola began to be less visible on day 3 where the moisture content is 2.31%, which is Profile 3. The increase in concrete MC affects the GPR in detecting steel reinforcement. Variation of water content causes the propagation velocity of electromagnetic waves to be less accurate. Hyperbola that are less visible will cause the determination of steel reinforcement depth to be difficult.

Dielectric value based on the moisture content in concrete

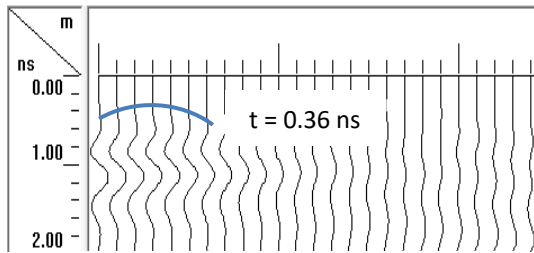
In order to determine the dielectric value at different MC, the electromagnetic (EM) velocity must be estimated first. The EM velocity can be estimated based on the two-way travel time through hyperbola fitting. Hyperbola fitting is the most common method to estimate the wave velocity. When there is a steel reinforcement in a concrete, it is easy to estimate the velocity using a hyperbola fitting since there is a hyperbola on the radargram (Figure 10). Hyperbola are fitted on the first reflection of steel reinforcement, which is the steel reinforcement with a depth of 25 mm. Therefore, the velocity of electromagnetic waves can be calculated by using equation (1). After the electromagnetic wave velocity is obtained, the dielectric value can be calculated using equation (2).

Table 4 shows the two-way travel time at various % MC. The presence of water in the concrete has shown a significant change in the reflected wave parameters. The electrical properties of a medium can be determined based on travel time of the EM wave. The GPR electromagnetic wave travel time increases, when MC increases. The two-way travel time for relative MC 0 % is 0.36 ns, while for concrete that has been immersed after 9 days with 2.54 % moisture content is 0.53 ns.

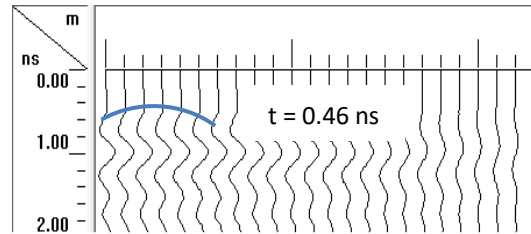
Table 4: Dielectric value based on moisture content (%)

Days	Moisture Content (%)	Two-way travel time (ns)	Velocity (m/ns)	Dielectric value (ϵ)
0	0	0.36	0.1389	4.67
300	1.06	0.37	0.1351	4.93
600	1.32	0.37	0.1351	4.93
1800	1.45	0.38	0.1316	5.19
3600	1.58	0.39	0.1282	5.48
7200	1.67	0.40	0.1250	5.76
10800	1.75	0.40	0.1250	5.76
14400	1.80	0.41	0.1220	6.05
180000	1.84	0.42	0.1190	6.35
21600	1.93	0.43	0.1163	6.67
193200	2.27	0.46	0.1087	7.62
268500	2.31	0.47	0.1064	7.95
432000	2.35	0.49	0.1020	8.65

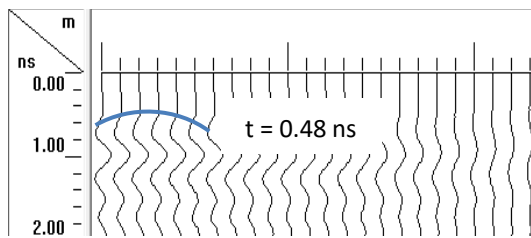
527580	2.45	0.50	0.100	9.00
622200	2.50	0.52	0.096	9.73
777600	2.54	0.53	0.094	10.11



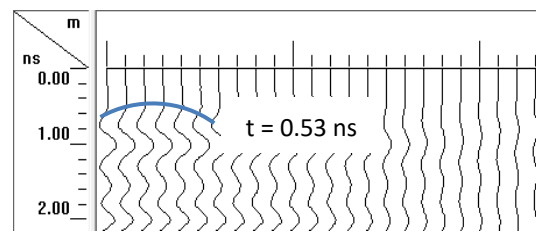
Radargram 1: Dry concrete samples
Relative moisture content % = 0%



Radargram 2: Concrete samples after 3 days of immersion
Moisture content % = 2.31 %



Radargram 3: Concrete samples after 9 days of immersion
Moisture content % = 2.35 %



Radargram 4: Concrete samples after 5 days of immersion
Moisture content % = 2.54 %

Figure 10: Radargram of two-way travel time

Figure 11 shows that the velocity of GPR electromagnetic waves decreases as MC increases. MC in the concrete sample has a significant impact on the propagation of EM wave velocity, where the velocity decreases. Based on the study, the velocity of the EM wave at 0% relative MC was 0.1389 m/ns, while at 2.54% MC was 0.094 m/ns. This is because EM waves move slower when propagating in concrete with higher MC, compared to dry concrete. The relationship between the GPR EM wave velocity and MC is:

$$\varepsilon = -0.0031MC + 0.1439 \quad (3)$$

where the % MC are between 0 to 2.54%. The relationship is inversely proportional where the EM velocity of GPR decreased when the MC in the concrete increased. Sbartai et al. al (2006) also shows an inversely proportional relationships based on Figure 1.

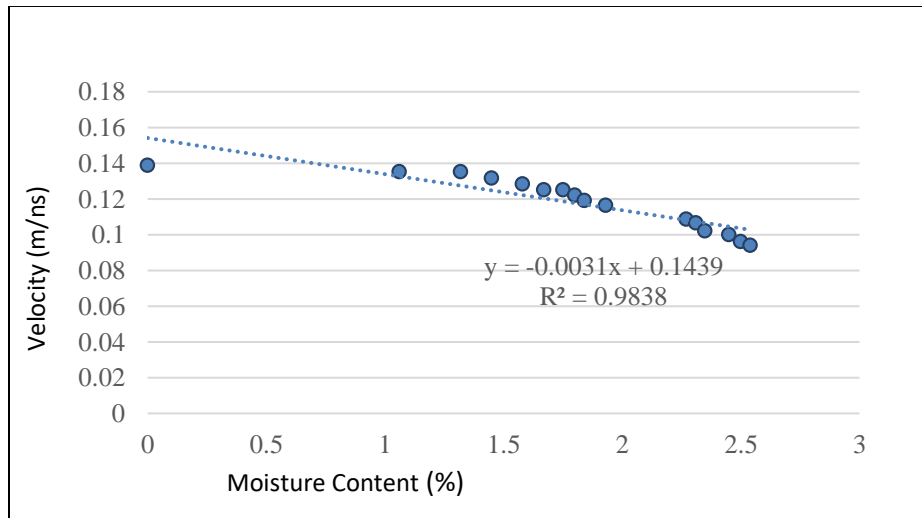


Figure 11: Electromagnetic wave velocity vs moisture content (%)

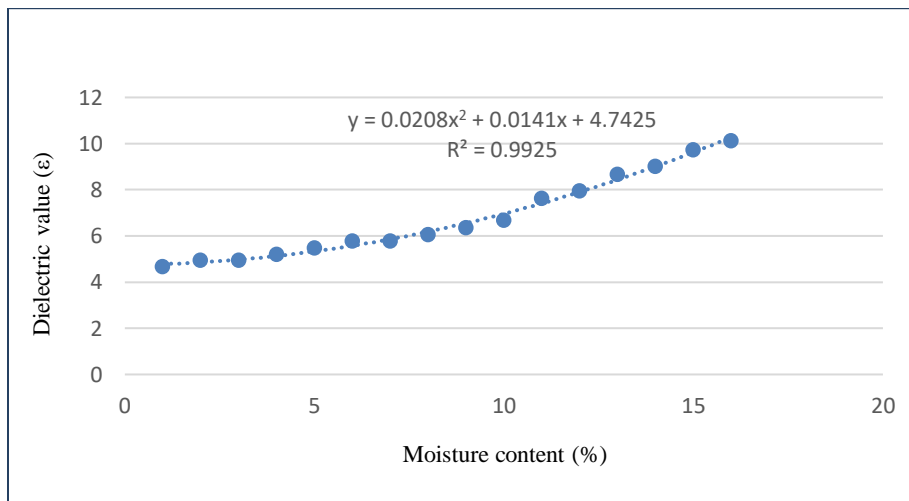


Figure 12: Dielectric value (ε) vs MC (%)

The reduction of GPR's EM wave velocity thus affects the dielectric value (equation (2)). The reduction of EM wave velocity due to the presence of MC results in high dielectric value. Based on Figure 12, the dielectric value increases when the %MC increases. The dielectric value is 4.67 in dry concrete, and 10.11 in sample with 2.54% MC. The dielectric value range obtained is within the range given by ASTM D-6432, which is 5-10 for concrete. The relationship between the dielectric value and the MC is:

$$\epsilon = 0.0208x^2 + 0.0141MC + 4.7425 \quad (4)$$



where % MC are between 0 to 2.54%. The relationship is polynomial which indicates a strong relationship between dielectric value and MC. Leucci (2012) (2012) also obtained a polynomial relationship between moisture content and dielectric value based on Figure 4.

Determination of steel reinforcement diameter

The diameter of steel reinforcement is (Lakshmi et al. (2016)):

$$\frac{E}{2} = \frac{\lambda}{4} + \frac{H}{\sqrt{\epsilon+1}} \quad (5)$$

$$R = \frac{L-E}{2\pi} \quad (6)$$

where, E = radius energy, λ = wavelength of the radar energy, H = depth from the surface to object, ϵ = dielectric value, L = length of scan, R = radius of steel reinforcement.

To obtain the length of scan, L the *GPRViewer* software is used to determine the number of scans based on the amplitude. The number of scans obtained is 61, 72 and 101, based on the depth of steel reinforcement.

Table 5: Diameter or steel reinforcement

Moisture content (%)	Dielectric value (ϵ)	Steel reinforcement (mm)	E	L	D (mm)	Different (%)
0	4.67	12	11.47	15.25	12.15	0.3
		16	14.41	18	11.43	-28.56
		20	19.45	25.25	18.46	-7.7
1.06	4.93	12	11.43	15.25	12.15	1.25
		16	14.3	18	11.78	-26.38
		20	19.23	25.25	19.16	-4.2
2.31	7.95	12	11.05	15.25	13.37	11.42
		16	13.39	18	14.67	-8.32
		20	17.4	25.25	24.99	24.95
2.35	8.65	12	10.98	15.25	13.59	13.25
		16	13.24	18	15.15	-5.32
		20	17.1	25.25	25.94	29.7
2.45	9	12	10.96	15.25	13.66	13.83
		16	13.17	18	15.37	-3.94
		20	16.96	25.25	26.39	31.95
2.5	9.73	12	10.9	15.25	13.85	15.42
		16	13.04	18	15.79	-1.31
		20	16.7	25.25	27.22	36.1
2.54	10.11	12	10.88	15.25	13.91	15.92
		16	12.98	18	15.8	-1.25
		20	16.58	25.25	27.6	38



Table 5 shows that the presence of MC in concrete gives a high percentage difference in determining the size of steel reinforcement compared to dry concrete. For dry concrete, the percentage difference (%) from actual diameter are 0.3% for 12 mm, -28.56 for 16 mm and -7.7% for 20 mm. The highest percentage difference for 16 mm reinforcement occurs due to the close vertical spacing between the steel reinforcement which is about 35 mm. Referring to Figure 6, if there are two layers of steel reinforcement, the second layer detection depends on the distance to the first layer. The vertical spacing of 35 mm might still be insufficient for GPR to detect two layers of reinforcement and causes the measurement to be inaccurate.

The percentage difference of reinforcement diameter to actual size increased when MC increased. The percentage difference at 2.54% moisture content is 15.92% for size 12 mm, -1.25 for size 16 mm and 38% for size 20 mm. This is because MC will cause attenuation of amplitude signal to occur and reduce propagation of EM wave. The wave attenuation occurs when there is a reduction in wave signal strength during transmission and reduces penetration of EM waves. The reduction of wave signal strength occurs due to the presence of MC which causes propagation of electromagnetic wave velocity to be less accurate. In addition, the equations (5) and (6) used to obtain the size of the steel reinforcement also do not take into account the MC could also contributes to the high percentage difference of the diameter.

Conclusion

The aim of this study is to focus on the effect of MC on GPR electromagnetic wave signal detection in determining the depth of steel reinforcement. The hyperbola reflection starts to fade when MC increases, which can cause the depth determination to be difficult. The dielectric value obtained in this study are in the range of 4.67 to 10.11, which is within the range dielectric values given in ASTM D-6432, which is 5-10 for concrete. The determination of reinforcement diameter has high percentage of error, up to 38% when there is an increasing MC in the concrete. Thus, further studies need to be done by taking other factors such as MC and spacing of reinforcement to obtain more accurate measurement of steel bar sizes using GPR method.

Acknowledgement

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SOUND INSERTION LOSS OF KENAF AND ARENGA PINNATA

MA Madlan¹,
Mohd Adzrie²,

FM Noor³,

MH Zainulabidin³,

NA Azmir³,

S Hassan³,

MF Sies³,

Tamilarasu A/L Maniam³

¹Faculty of Engineering, Universiti Malaysia Sabah (Email: amran.madlan@ums.edu.my,)

²Faculty of Engineering, Universiti Malaysia Sabah

³Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia

Abstract: Heat Ventilation Air Conditioning System (HVAC) is designed to control the environment inside of residential, commercial or industrial buildings by controlling temperature of a room through heating and cooling. However, due to its mechanism, noise is produced in the system and reaches the people inside the building, thus causing distraction, discomfort and uneasiness. There are HVAC silencers in the market; however, the sound absorbing material used is of mineral wool types. In this study, the ducting silencer with the sound absorptive material that made of Arenga Pinnata, Kenaf and composition of these both materials were tested to identify its performance. The experiment was carried out in a testing apparatus that follows the ASTM E477-99 standard. Insertion loss was analysed at the end of the study. From the overall result and comparison, the insertion loss of Kenaf is averagely better than Arenga Pinnata, that is 97.5% higher than Arenga Pinnata. When composition of Arenga Pinnata and Kenaf is used, Kenaf plays important role in sound insertion loss, where when Kenaf composition increase, it increases the sound insertion loss capability.

Keywords: Kenaf, Arenga Pinnata, Ducting System, Insertion Loss

Introduction

The Heat Ventilation Air Conditioning (HVAC) system is used in most building to regulate temperature, humidity and supply fresh air from outdoor. HVAC have a bigger responsibility in maintaining comfort for occupants inside the building, but it is also created a negative effect to the person in the building, where noise created by HVAC system. HVAC system produce noise since the fan operates in the system and impact of air through the duct system create noise. The noise transmitted in the HVAC system through the HVAC duct and also directly from the noise source to the room or building. The noise that transmitted through the HVAC duct wall will create uncomfortable to people in the building. The noise that produced in HVAC system must be reduced, so the room remains comfortable. The material that mostly used as the dissipative silencer in HVAC system is Rockwool and Glass wool. The Rockwool and Glass wool that are usually used as dissipative silencer also have some disadvantaged. Rockwool and Glass wool are not bio gradable and its dust and fiber are bad for human health.

Literature review

Arenga Pinnata or Ijuk is a natural fiber that obtained from the palm sugar tree (Ismail et al., 2010). Arenga Pinnata is available in Southeast Asia like Indonesia and Malaysia. The products that mainly made are used in traditional application such as rope, broom, carpet and sofa cushion (Bachtiar, 2010) and is obtained directly from natural resources and it is also cheap.

Arenga Pinnata fiber is collected from the palm tree (Bachtiar, 2010) and cleaned with water then let it dry at room temperature. The dry fiber used in the applications such as dissipative silencer (Ismail et al., 2010). Arenga Pinnata has been tested sound absorption ability and it has shown ability as dissipative absorber. From the Figure 1, when thickness of Arenga Pinnata fiber is increase the sound absorbing coefficient also increases (Ismail et al., 2010).

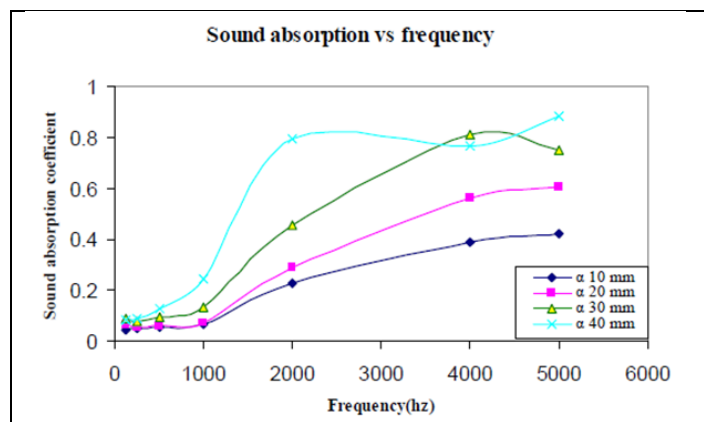


Figure 1: The sound absorption of Arenga Pinnata fiber (where α is the thickness of the Arenga Pinnata) (Ismail et al., 2010).

Kenaf is a type of hibiscus plant and is a member of the Malvaceae family. It's can grow to a height of 2.5m to 5m in 4 to 5 months. Kenaf mainly cultivated for its fiber. The fiber from Kenaf has best resemble fiber and suitable for jute fiber. Fiber strands are 1.5m to 3m long. It is usually used to make rope, canvas, sacking, carpet backing and fishing net (Gowda, 2010).

Kenaf is a natural fiber which have advantages such as renewable, environmentally friendly, low cost, low density, flexibility of usage and biodegradable. Kenaf is one of the important sources of fiber in many applications. Kenaf have ability to be a reinforced fiber in thermosets and thermoplastic composites (Mohd Yuhazri, 2010).

Kenaf is chosen to be material for dissipative silencer for this study because Kenaf have the ability to absorb sound, where the sound absorbing coefficient of 0.74 for silencer thickness of 50mm according to Asdrubali (2006)'s.

A research carried out by D'Alessandro and Pispola (2005), Kenaf show an average absorption coefficient 0.85 in the 500Hz-5000Hz range and equal to 0.65 in the 100Hz-500Hz range as shown in Figure 2. Although Kenaf showed a slightly poor performance as sound absorber, it can be an alternate to the traditional mineral wool blanket for thermoacoustic application since its beneficial properties of low impact on human health and on the environment.

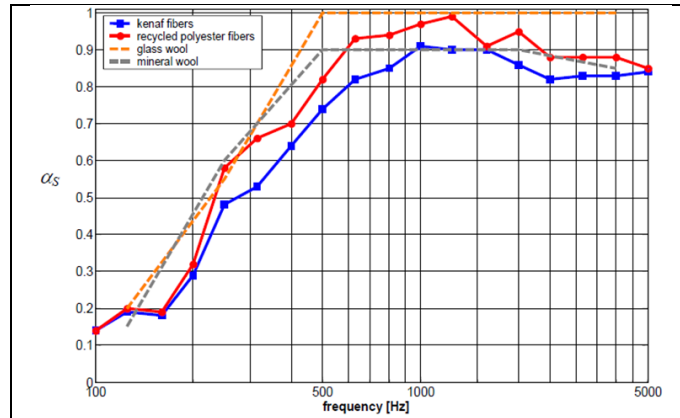


Figure 2: Third-octave band sound absorption coefficient α_s of Kenaf and recycled polyester fibrous blanket in comparison with traditional fibrous absorber (D'Alessandro & Pispola, 2005)

Dissipative silencers consist of sound absorbing materials. Silencer can be active or passive type. Active type silencer is use noise cancelling techniques by using microphones, loudspeakers and signal processing to generate sound waves out of phase with the objectionable noise. Passive silencer is absorber type, where the noise is absorbed. Passive silencer usually used in HVAC system (Reid, 2006).

Another type of silencer usually used is baffle silencer. Baffle silencer installed parallel to gas flow. The silencer can be installed in many ways of configuration. Each type of configuration has its own advantages and disadvantages (Madlan, 2017). According to Rairat (2003), thickness of the absorptive material and spacing of absorptive material can affect the performance of silencer. The different thickness of noise absorptive material has different effect on silencer performance with varying range of frequency.

On the studies carried out by Ruggero, Davide and Corrado (2008), sound attenuation in the ducts line with granular material tested with varying thickness of absorbing lining. The experiment also conducted with linings of mineral wool, which traditionally used for sound absorption in lined duct. The result compared the insertion loss between granular material and mineral wool. From the Figure 3, it shows that the maximum insertion loss becomes smaller steadily as the thickness of the material increases.

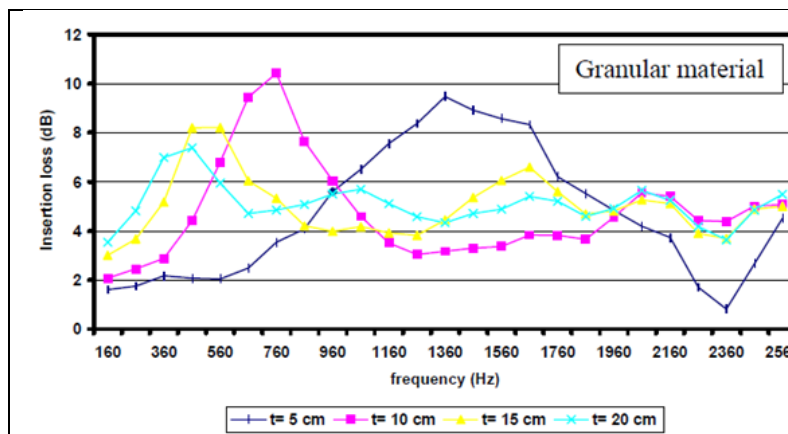


Figure 3: Spectral insertion loss for rectangular ducts lined with granular material of different thickness (Ruggero et al., 2008)

From the result in Figure 4, it shows that the insertion loss seems independent of the thickness, in the frequency ranged tested for thickness higher than 50mm. Mineral wool has shown greater insertion loss than granular material. However, the granular material has shown good insertion loss at certain point of frequency. The insertion loss that get using granular material is quite good enough for it to be used in practical application.

The mineral wool traditionally used as sound absorption material but when it comes to health concern and resistance to environmental aggression, granular material can be an alternative to it (Ruggero et al., 2008).

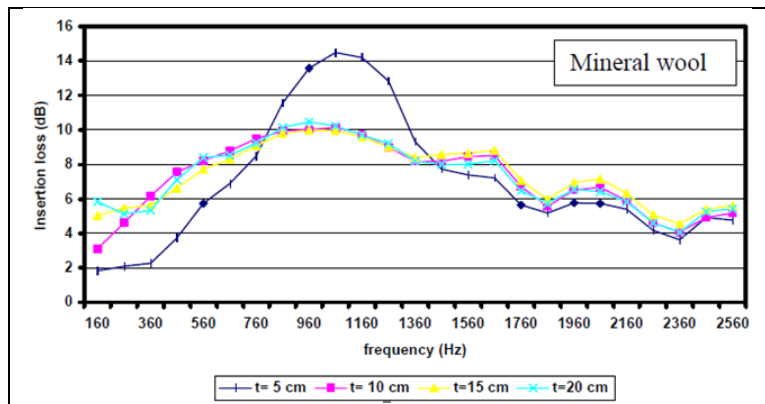


Figure 4: Spectral insertion loss for rectangular ducts lined with mineral wool of different thickness (Ruggero et al., 2008)

National University of Singapore, School of Building and Real Estate conduct a test which is Acoustic Research Laboratory, Report No 990405 (Acoustic Research Laboratory). The test is about insertion loss when a silencer made by material glass wool is used. The length of silencer fixed to 3m and the diameter is varied to 50mm, 200mm and 250mm in the test. The test carried out within the frequency of 63Hz to 8000Hz.

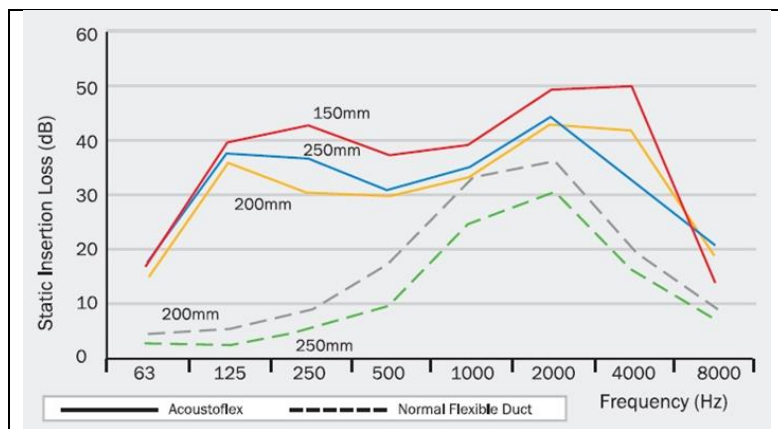


Figure 5: Graph of insertion loss versus frequency of noise of Acoustoflex’s silencer with three different diameters and two different diameters of normal flexible duct (Acoustic Research Laboratory).

From the result in Figure 5, it shows that silencer with different diameter have different insertion loss at specific frequency. The silencer by Acoustoflex with 150mm has the highest insertion loss among all other silencer tested. From the result, it can observe that silencer with lower diameter have higher insertion loss for both Acoustoflex’s silencer and normal flexible duct, although Acoustoflex does not specify the material used for both silencer type (Acoustic Research Laboratory).

Methodology

ASTM standard E477-99 is followed and most procedure carried out based on that standard. The dimension of the testing apparatus is based on testing apparatus in ASTM E477-99 which is scaled down. Figure 6 shows the configuration of dissipative silencer. There are 7 types of samples tested, which are 60g Kenaf, 60g Arenga Pinnata, 30g Kenaf and 30g Arenga Pinnata, 30g Kenaf and 40g Arenga Pinnata, 30g Kenaf and 20g Arenga Pinnata, 30g Arenga Pinnata and 40g Kenaf, 30g Arenga Pinnata and 20g Kenaf. Sound absorptive material’s dimension are 250mm length, 150mm width, and 15mm thickness. Preparation of sound absorptive material is done by compress the fibers, which is Kenaf and Arenga Pinnata with selected mass in compression mold and using Latex as adhesive. A TES Sound Analyzer is used to measure noise at various 1/3 octave frequency at the data collection point. The complete setting of apparatus is shown in Figure 7. Figure 8 shows the real testing duct during conducting experiment.

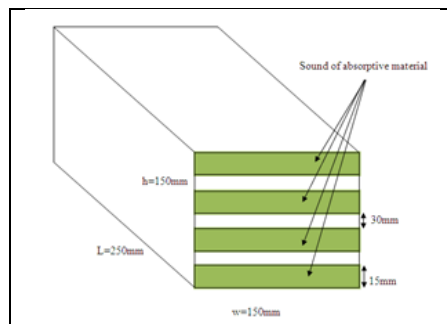


Figure 6: Configuration of dissipative silencer

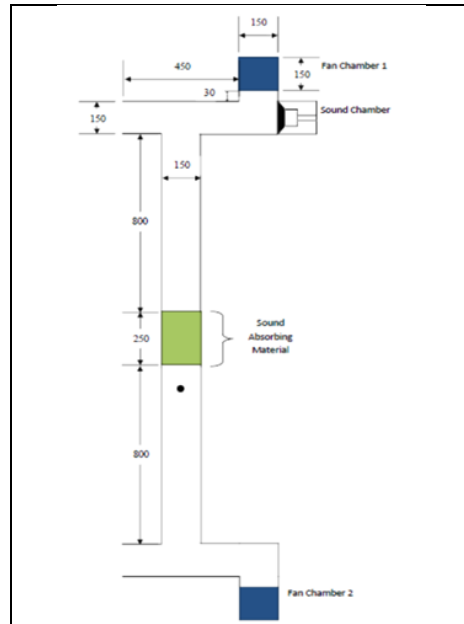


Figure 7: Setting of testing apparatus



Figure 8: Testing duct

Result and discussion

From the overall data, sound absorbing materials Kenaf, Arenga Pinnata and composition of both materials show ability to absorb sound. From the comparison of all 60g sound absorptive material, Kenaf have higher insertion loss than Arenga Pinnata. The trend of both graphs almost the same. The graph of insertion loss versus frequency for all 60g sound absorptive material shown in Figure 9. From the comparison of one material's mass as constant and other material mass varying, the relationship between the material and which material majorly effect the sound absorbing performance can be identified. The graph of insertion loss versus frequency for Arenga Pinnata's mass constant is shown in Figure 10 and Kenaf's mass as constant on Figure 11.

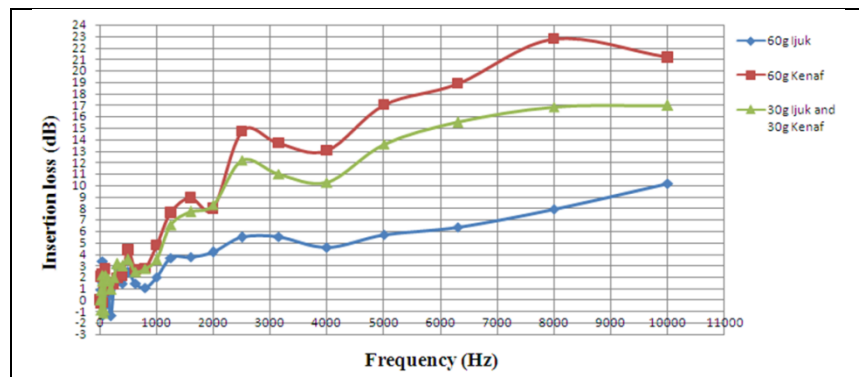


Figure 9: Insertion loss of 60g sound absorbing material

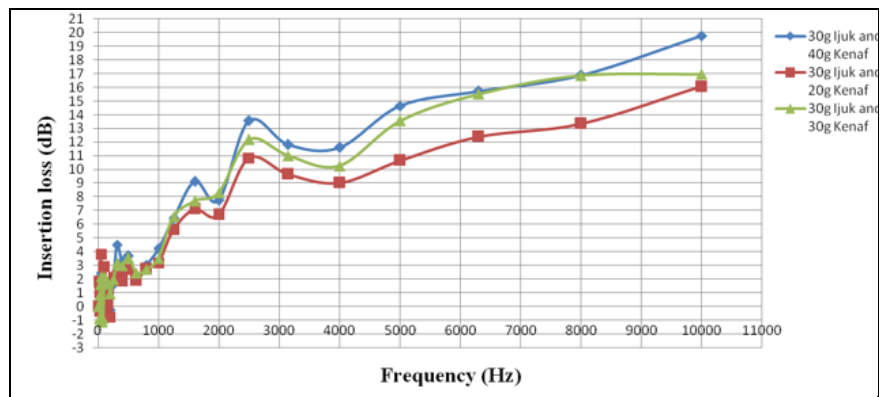


Figure 10: Insertion loss of Arenga Pinnata as parameter

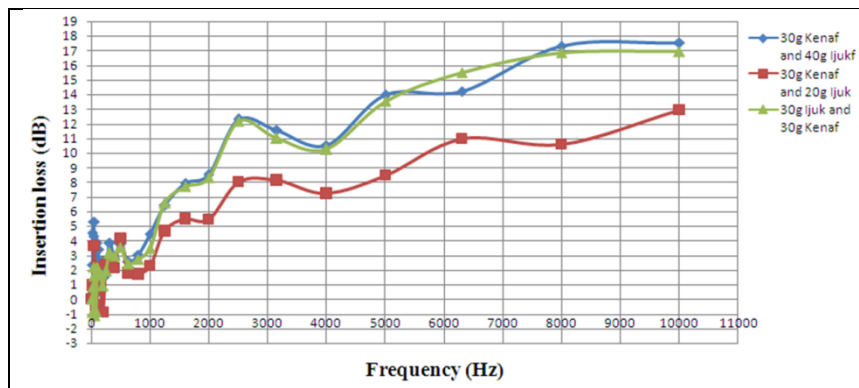


Figure 11: Insertion loss of Kenaf as parameter



Conclusion

As a result from this study, the trend of insertion loss at 1/3 octave frequency of dissipative silencer made of Arenga Pinnata and Kenaf shows the insertion loss is lower at the lower frequency and as the frequency increase, insertion loss also increases steadily until 10kHz. Insertion loss is higher when the sound absorptive material have mass percentage of Kenaf higher. 60g Kenaf has the highest insertion loss. Both Kenaf and Arenga Pinnata have the ability to absorb sound and this study shows that these natural fibers can make use as ducting silencer.

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STUDY OF PIVOT PANEL MECHANISM ON THE SELF START-ABILITY OF A DARRIEUS WIND TURBIN

CHEONG THEAN SENG,
MOHD SUFFIAN MISARAN¹,
MOHD KAMEL
WAN IBRAHIM

¹ Mechanical engineering, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah.

Abstract : *In South East Asia countries such Malaysia, wind turbine is generally not suitable to be used in large scale to generate electricity due to inconsistent wind speed and suitable land site availability. However, a small scale application is of preference as the wind speed in the region lies within the low speed range of approximately $2-5 \text{ ms}^{-1}$ with intermittent highs up to 8 ms^{-1} . The performance of Vertical Axis Wind Turbines (VAWTs) is known to be better compared to Horizontal Axis Wind Turbines (HAWTs) in urban conditions due to its omni-directionality, which allows it to operate in fluctuating turbulent wind conditions. However, the major drawback of VAWTs is the inability to self-start under low wind speed conditions. Hence, the objective of this work is to investigate the Pivoting Panel Mechanism (PPM) which aims to assist VAWT models to self-start at low wind speed condition. Three sets of PPM width configurations (70mm, 80mm, 90mm) are used to study the effect of increasing the pivot panel surface area on the VAWT performance. Performance test showed that the PPM model improved the power coefficient values at the tip wind speed range of $\text{TSR} < 0.75$ ($\text{PPM } 70\text{mm} > 80\text{mm} > 90\text{mm}$). Further investigation revealed that the larger PPM surface area (90mm) was able to assist the VAWT model to achieve a shorter RPM response time at wind speed of $v = 2.5 \text{ ms}^{-1}$ and 2.9 ms^{-1} . These findings have considerable implications for future researches for the optimization of PPM design parameters and its adaptations in VAWT turbine design.*

Keywords: *hawt, low wind speed, wind turbine*

Introduction

The global power sector is witnessing a gradual transition from conventional thermal power-generating sources toward renewable energy technologies. The establishment of supportive policies and regulatory frameworks in various countries, particularly by China and India, has facilitated the growth of renewable energy in the past decade. Therefore, the falling cost of solar and wind electricity has led to a boom in the construction of utility-scaled power projects (Global Data Energy, 2018). Consequently, global investments in renewables from 2001-2018 consistently exceeded USD\$200 billion (McCrone and Mosiener, 2018).

One of the potential renewable energy sources for Malaysia is wind energy. There are many sites in Malaysia that are geographically strategic for large scale electricity power generation, which are Kudat, Kota Bharu, Sandakan, Miri and Kota Kinabalu. Albani, et al (2013) conducted



a simulation analysis using a 22kW rated power wind turbine using the WindPro software to estimate the wind potentiality in Malaysia based on the METAR data available from 2005-2011.

Simulation results yielded that Kudat is predicted to generate the highest annual energy production at 14.6 MWh/year as well as highest capacity factor and full load hour at 7.6% and 661 hours/year respectively, which is made possible by the highest wind power density of 21 W/m² produced and Weibull scale parameter for wind speed of 2.8 ms⁻¹. On another perspective, it has been revealed in a study that the rate of urbanization in a country has a direct negative influence on urban wind speeds and the surrounding areas (Liu, 2018). Statistics revealed that the rate of increase of urbanization rate is linear, from 68.36% in 2007 to 76.01% in 2017 (Greenfield, 2018). Therefore, the average wind speed for Malaysia may be lower than the predicted range of (<2ms⁻¹) in most areas in Malaysia. The commercialization of the wind turbines requires a minimum cut-in speed of 4 ms⁻¹ for electricity power generation (Chinnasamy, 2015). As a result, small-scaled wind energy harvesting is potentially more practical to be applied in Malaysia, particularly in Sabah.

Literature review

Low wind speed wind turbine

Wind turbines are categorized into two major types, which are the Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT). The difference between the HAWT and the VAWT is the orientation of the axis of rotation of the main shaft which is connected to the wind turbine blades. HAWT produces more power output than VAWT, but it requires high wind speeds for it to function operationally and to yield maximum performance. Therefore, HAWT is not a practical choice for the renewable energy industry in Malaysia due to the low average wind speed (<2ms⁻¹). On the other hand, VAWT design models are relatively quieter, produces less stress on the support structure and most importantly omni-directional. In addition, VAWT has the capability to generate power without requiring much wind, enabling the generator and transmission mechanism to be installed close to the ground where wind speed is low. This allows for relatively easier maintenance processes than HAWT, which are installed at the top of the tower at a height potentially reaching up to 126 m. Therefore, the development of VAWT technology in Malaysia is more feasible than HAWT predominantly due to its ability to generate power at low turbulent wind speeds in any wind direction (Kumara, 2017).

There are two major types of VAWT, which are the Savonius rotor and the Darrieus rotor. The Darrieus rotor is a lift-type VAWT, featuring the employment of aerodynamically shaped rotors which facilitates the generation of lift force to rotate the turbine operationally. The use of airfoils as the blades of the rotor multiplies the wind speed passing through it, giving it a large TSR ratio of more than 1. Therefore, the Darrieus rotor is more efficient than the Savonius rotor, but only at high wind speed conditions. The Darrieus rotor has a major drawback of low initial torque generation, and therefore has difficulty to self-start at low wind speed conditions. Therefore, many researchers had attempted to come out with innovative design such as integrating the Savonius rotor into the Darrieus rotor to create a new VAWT hybrid design model to overcome the weakness of the Darrieus rotor or improving the design of the Darrieus blade itself (Oskarsdottir, 2014; Chua et al., 2014; Jamanun et al., 2017; Misaran et al., 2017). Passive and active pitch mechanism are also incorporated into the Darrieus design model to enhance the self-starting capability and to optimize the efficiency.



Abid, et al (2015) designed, constructed and tested a 3-bladed Darrieus turbine with an external Savonius turbine mounted on top of it. Experimental results showed that the slight Savonius modification enabled the turbine design to self-start more easily at low wind speed conditions. Sharma, et al (2013) attempted to measure the performance of the designed 3-bladed Darrieus-Savonius turbine using the pitot-tube wind tunnel set-up with 5 various overlap ratios ranging from 10.8-25.8%. The experimental results revealed that the C_p increases as the overlap ratio increases until it reaches an optimum point of 0.53 at 0.604 TSR and 16.8% overlap, concluding that the hybrid design is capable of self-starting. Another hybrid Darrieus-Savonius turbine design is proposed, which latter component is attached at the centre of the shaft. The hybrid design combines the relatively higher efficiency features of the former and the self-starting capabilities of the latter. The performance parameter chosen in the research is the coefficient of power, C_p . The experimental analysis was conducted using a wind tunnel set-up, which results showed that the hybrid turbine yielded a relatively higher C_p value (0.23) in comparison with the Darrieus turbine (0.21) and the Savonius turbine (0.19) at low wind speed conditions ($2-4 \text{ ms}^{-1}$). However, the of the C_p of the hybrid turbine showed a significant decrease at high wind speed condition ($>4 \text{ ms}^{-1}$), which may be attributed to the overall heavier structure and predominantly the large drag force exerted on the Savonius component (Kavade and Ghanegaonkar, 2017).

Kiwata, T. et al (2010) developed a unique VAWT model equipped with a double crank link mechanism constituting the variable pitch blade angle mechanism, imbuing the design with smooth wind directionality. The performance parameter is dependent on the blade pitch angle amplitude, the number of blades and the airfoil profile. The constructed prototype is tested experimentally in a wind tunnel set-up. Results showed that the self-start capabilities of the design is same as the fixed pitch blade mechanism, but yielded a significant increase of rotational speed, achieving a maximum C_p of 0.22 at 1.2 TSR. Portillo et al (2016) designed, simulated and constructed a VAWT model with an active pitch mechanism, which is guided by a wind vane mounted on top of the main shaft. The Double Streamtube Model is utilized to predict the performance of the turbine using MATLAB and ANSYS software. The experimental results showed that the turbine was able to self- start at low wind speed range (3.6 ms^{-1}) and capable of generating electric power of 120W at high wind speed conditions (up to 7.6 ms^{-1}) with an efficiency of 35%. Another research proposed a design model consisting of the combination of a conventional five straight-bladed Darrieus VAWT with flat-plated flap mechanism. The resultant hybrid VAWT design successfully self-started under low wind speed conditions at 1 ms^{-1} and recorded an average increment of 2-5% power output compared to the conventional Darrieus VAWT. However, the hybrid design with the fixed flap mechanism recorded a drop in performance at higher wind speed conditions ($>3 \text{ ms}^{-1}$) (Hasnuddin, 2018).

According to World Weather Climate and Information (2019), it is shown that the average wind speed in Sabah is approximately 2.0 ms^{-1} . Therefore, it is a necessity for designed VAWTs to achieve self-start capability in the low wind speed range of $2-5 \text{ ms}^{-1}$.

Model description

Design of Pivot Panel Mechanism (PPM)

The pivoting panel concept is adopted by Yoon (2013), who designed the panels in such a way that the panels are oriented 90° with respect to the supporting arm in the leeward direction and flaps up in the windward region. Therefore, a net torque is produced due to this configuration,

providing additional drag forces which can potentially boost the power output and increase the self- starting capacity of VAWT design models. The counterweight mechanism concept is adopted from Borkar (2018), who designed a tilted flap mechanism that passively adjust the pitch due to the motion of wind itself whereby the flap is close up in leeward region by the action of gravity and open up in the windward region utilizing the action of wind. Thus, a hybrid wind turbine as shown in figure 1 is designed and assessed.

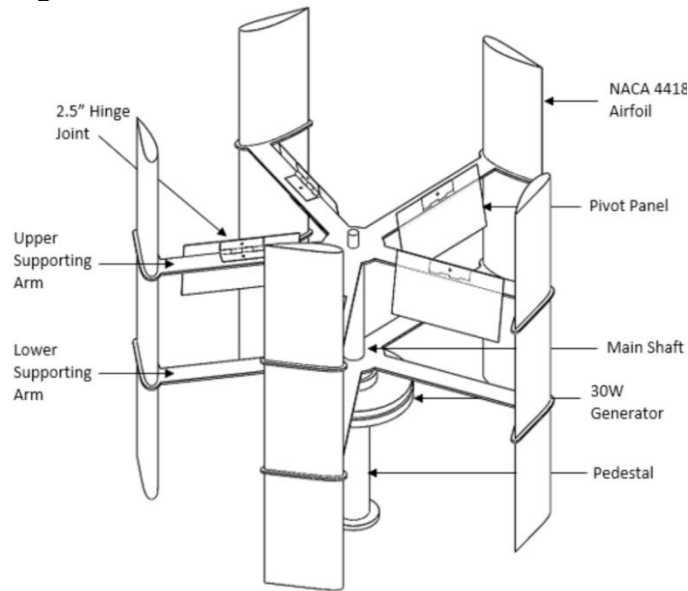


Figure 1: VAWT with pivot panel

Experimental setup

Four different configurations of the Darrieus VAWT model as shown in table 1 were tested; in order to determine the effect of increasing the plate surface area (aspect ratio) in contact to the wind on the response time and power coefficient; within the wind speed of up to 5 ms^{-1} .

Table 1: Pivot panel configuration

Material: Aluminium Alloy 1060				
Configurations	Length, L (mm)	Width, B (mm)	Aspect Ratio (L/B)	Thickness (mm)
Pivot Panel 1	150	70	2.14	0.4
Pivot Panel 2	150	80	1.89	0.4
Pivot Panel 3	150	90	1.67	0.4

Six air blowers are arranged in a 2x3 configuration as shown in Figure 2. The air blowers used have a diameter of 30 cm, with a rated air flow rate of $62 \text{ m}^3/\text{min}$ and a rotational speed of

2900 rpm. The distance between the Darrieus VAWT model and the air blowers are varied to obtain different wind speeds that is acting on the model, which are assigned from 1m to 13 m in steps of 2 m. The average wind speed for the 7 sets of distances are measured using the digital hand-held anemometer while the turbine rotation speed were measured using wireless magnetic speedometer attached at the wind turbine shaft. The obtain wind speed and wind turbine rotation speed are used to calculate the tip speed ratio (TSR).

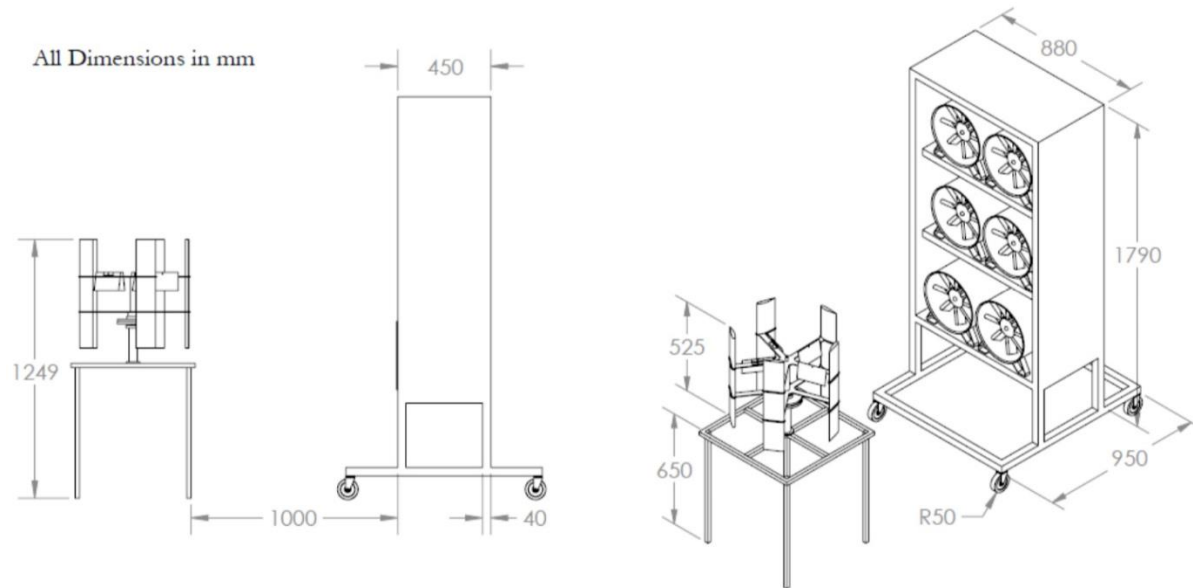


Figure 2: Experimental setup

Result and discussion

Effect of PPM on wind power performance

The PPM (70mm, 80mm, 90mm) configurations are compared as shown in Figure 3. It is noted that at the wind speed of ($V=3.8\text{ms}^{-1}$, 4.1s^{-1} , 4.7ms^{-1}), the power coefficient and power output of the PPM 90mm model is slightly higher than the 70mm and 80mm counterparts. The possible explanation to this experimental outcome may be due to the better ability of the pivot panel of width 90mm to flap up and down of the in the upwind windward and upwind leeward region respectively at higher stable RPM. The former flap up motion in the upwind windward region accounts for the unconstraint motion about the hinge pin, which may exert minimal opposite torque. On the other hand, the latter flap down motion in the upwind leeward region allows the incoming wind to exert positive torque. Since the PPM 90mm has a larger surface area in contact to the wind, therefore more positive torque is generated compared to the 80mm and 70mm PPM configuration (PPM 90mm > PPM 80mm > PPM 70mm) since the wind force impacting the pivot panels are sufficiently high for the PPM 90mm to flap.

However, it can be observed at the wind speed range of ($V=2.2\text{ms}^{-1}$, 2.5s^{-1} , 2.9ms^{-1} , 3.2ms^{-1}), the PPM 70mm yielded approximately similar power coefficient with PPM 80 mm, but slightly higher than PPM 90 mm. The possible reason of this occurrence may be due to the

decreasing ability of the pivot panels PPM 80 mm and 90 mm to flap up at $V < 3.2 \text{ ms}^{-1}$ (corresponds to lower stable operating RPM). Therefore, the induced opposite drag force especially for PPM 90 mm may be higher at stable operating RPM conditions compared to PPM 70 mm and 80 mm. Hence, this also suggest that the weight factor (Tong, 2010) and the ability of the pivot panel to flap collectively influences the power coefficient and the power output of the PPM VAWT model.

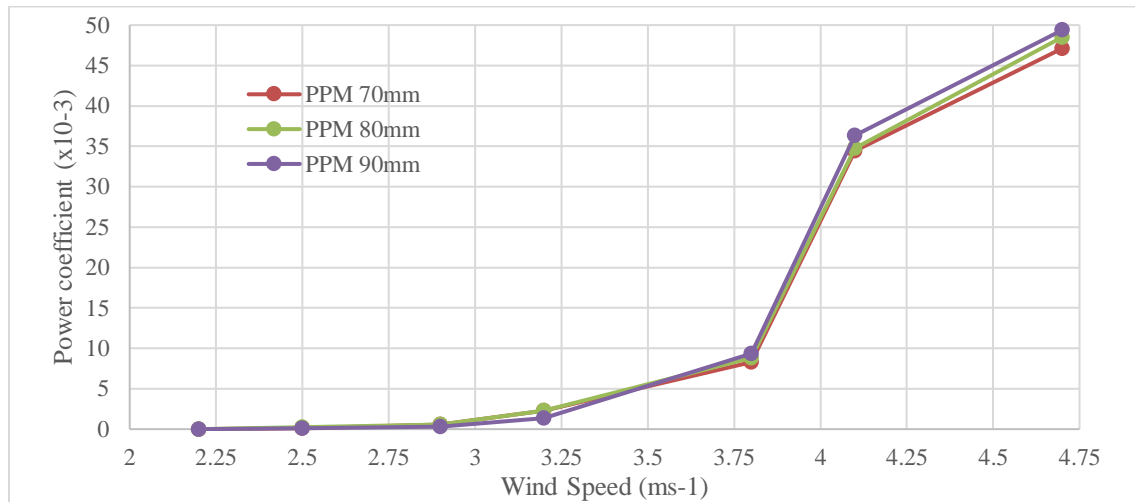


Figure 3 : Graph of Power Coefficient vs Wind Speed (PPM only)

The PPM models yielded a marginally higher power coefficient at approximately the range of $TSR < 0.75$ compared to a standard VAWT. For instance, the PPM 70 mm, 80 mm and 90 mm yielded a power coefficient improvement up to approximately 37%, 26%, 17% respectively compared to the standalone VAWT model at $TSR = 0.5$. Therefore, this suggest that the PPM model may enhance the self-start capacity of the VAWT model at $TSR < 0.75$, since it is observed in the experiment that the standard VAWT experience considerable delay to self-start at a wind speed range of $V < 3.2 \text{ ms}^{-1}$.

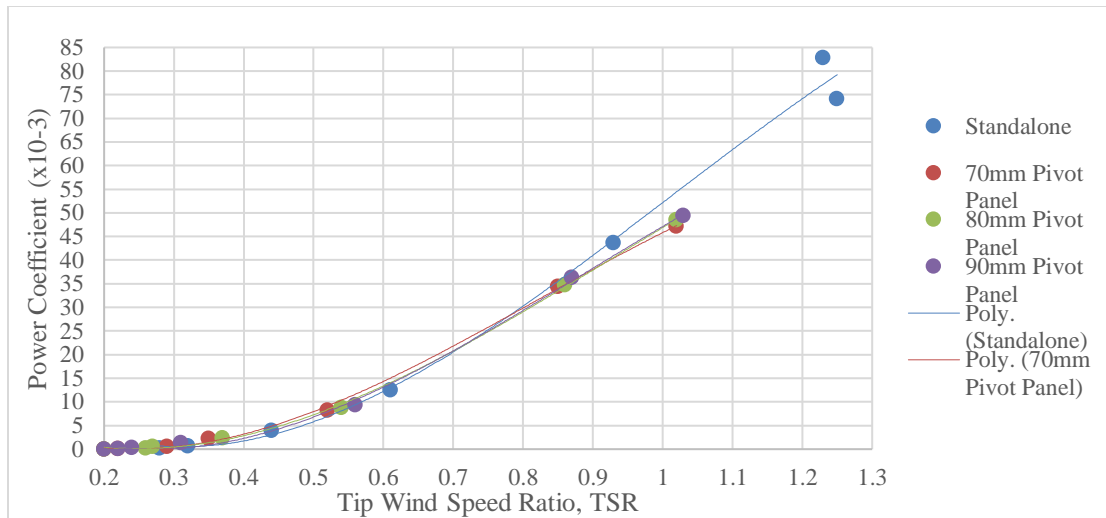
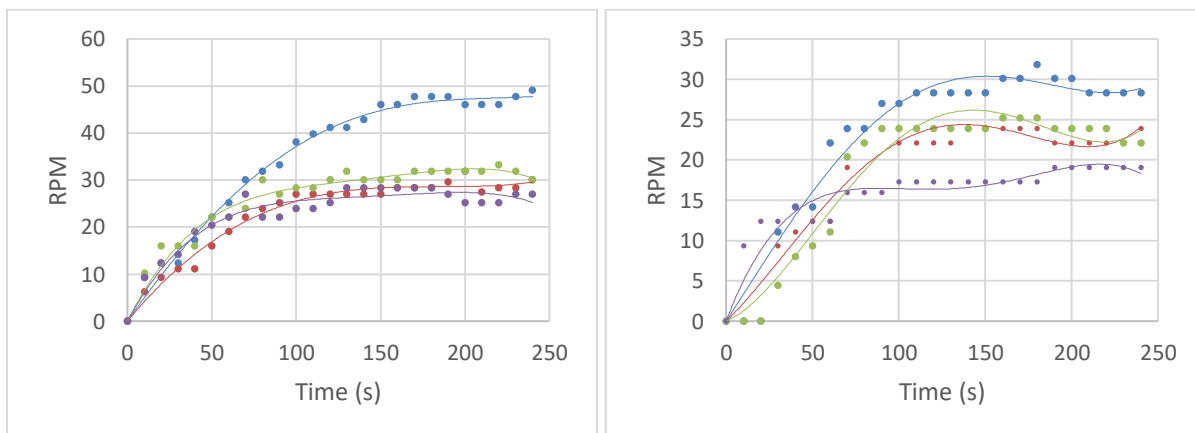


Figure 4 : Power Coefficient vs Tip Wind Speed Ratio (0.2<TSR<1.3)

Wind turbine response time at low wind speed

The wind turbine response time analysis shows how the turbine reacts to average wind velocity as shown in figure 5. The PPM model in figure 5(a) showed a slightly sharper rise of RPM compared to the standalone model (9.7 RPM) for PPM 80 mm (11.8 RPM, +21%) and PPM 90 mm (11.1RPM, +14%) at the wind speed of $v=2.9 \text{ ms}^{-1}$ at the initial 20 seconds (starting phase). This experimental data may be consistent with the experimental observations whereby the pivot panels in PPM 70 mm experience difficulties in flapping while the PPM 80mm and 90 mm can flap relatively well at the starting phase. This suggest that the PPM has the potential to assist the VAWT model to self-start to a higher speed at a shorter amount of time compared to the standalone model, provided that the pivot panel in the upwind windward direction can flap up in the starting phase to cancel out the generation of opposite torque.



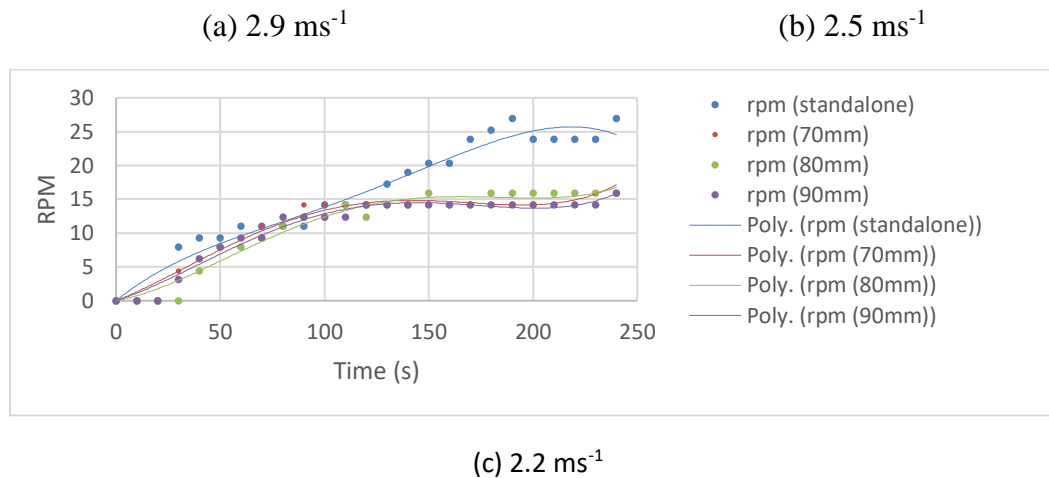


Figure 5: Wind turbine response time (240 seconds) at different low wind speeds

This phenomenon is further observed at 2.5 ms^{-1} as shown in Figure 5 (b); PPM 90 mm showed a slightly sharper RPM rise (8.8RPM, +28%) compared to the standalone model (6.9RPM) within the initial 20 seconds (starting-phase) while the PPM 80 mm and 90 mm configurations does not. This occurrence is quite consistent with the experimental observations whereby the pivot panels of the PPM 90 mm can flap well at the starting phase whereas the other plates in the other configurations pivoted relatively poorly. This may be attributed to the relatively larger surface area in contact to the wind for the 90 mm width plate compared to the 70 mm and 80 mm counterparts, corresponding to more wind force acting on the plate.

However, it is observed that for the wind speed of $v=2.2 \text{ ms}^{-1}$ as shown in Figure 5 (c), the sharp rise of RPM in the initial 20 seconds is not observed like the previous two cases discussed above. This occurrence is also consistent with the experimental observations whereby the pivot panels of the PPM (70 mm, 80 mm, 90 mm) demonstrate poor flapping ability at the starting phase, which in fact contributed to the occasional stalling of the PPM VAWT model as the experiment is repeated due to the opposite torque generated. The possible reason for this occurrence may be due to the insufficient wind force exerted on the 90mm pivot panel for it to flap up in the upwind leeward direction.

Conclusion

As a conclusion, this study have shown that both the PPM 80 mm and 90 mm VAWT models are able to assist the VAWT model to self-start at the wind speed of $v=2.9\text{ms}^{-1}$. On the other hand, only the PPM 90 mm model is observed to improve the self-starting capability of the VAWT model at the wind speed of $v=2.5\text{ms}^{-1}$ within the initial 20 seconds (starting phase). At the lowest wind speed of 2.2ms^{-1} , all the PPM VAWT models are observed to lack the ability in assisting the VAWT model to self-start. Power coefficient analysis of the turbine showed a relatively higher power coefficient at $\text{TSR}<0.75$. It is calculated that the PPM 70 mm ($C_p=8.0 \times 10^{-3}$), 80 mm ($C_p=7.3 \times 10^{-3}$) and 90 mm ($C_p=6.8 \times 10^{-3}$) yielded a power coefficient improvement up to



approximately (37%, 26%, 17%) respectively compared to the standard VAWT model ($C_p=5.8 \times 10^{-3}$) at $TSR=0.5$.

Acknowledgements

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STUDY OF WYEE-TEE DUCT DESIGN AT VARIOUS PROTRUSION AND GUIDE VANE LOCATION USING CFD

MOHD SUFFIAN MISARAN¹,
CHENG FANG SING,
MOHD ADZRIE RADZALI

¹ Mechanical engineering, Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah.

Abstract : *The design of the air ducting system in a HVAC system is crucial as it serve its main function of delivering desired air properties at optimum efficiency. However, air flow deficiency in the duct system can caused major issues in an HVAC system; building discomfort, high energy costs, increased noise levels, bad air quality, vibration, etc. One of the main factors in air flow efficiency is the fluid resistance which consist of; friction losses and dynamic losses. Numerous studies have been made to reduce effect of resistance especially at junctions and elbows of a duct system. The objective of this study is to investigate the characteristic of the wye tee duct with protrusion and guide vane installed using CFD method. A variance of the wye tee duct is introduced by installing protrusion and guide vane at various configuration. The flow characteristic is studied using CFD and the best efficiency of the configuration is observed. Simulation study shows that vane protrusion height $H=0.05$ m and guide vane position $L=0.3$ gave the best efficiency improvement at 22.29% at main duct section and 2.4% at the branch duct section. This study concludes that it is possible to further increase the wye-tee duct design efficiency with protrusion design and guide vane installation in the section.*

Keywords: Duct, HVAC, CFD

Introduction

Heating, ventilation and air conditioning system are one of the most important system in the construction of residential, landed house, school, hospital, office building etc. According to Wang. SK (1994), HVAC system functions includes; heating and cooling, air quality control (dehumidifying and humidifying, purifying and cleaning) and air ventilation. All these functions are realised thru the air handling unit, the duct system and the air diffuser outlet. The duct system is used in transferring and distributing the air to the various rooms inside a building. Friction and turbulence are an important factor affecting air flow rate in the duct system. In the case of solar chimney for ventilation and cooling application, a bad duct design can affect the air flow significantly (Ling et al., 2017). With the emergence of earth air pipe system for cooling, the system relies on efficient design of ducts to allow natural air flow to occur based on temperature difference (Darius et al., 2017). Thus, it is very important to address these factors and mitigate its negative effects to increase air flow efficiency and ultimately reducing operational cost (ASHRAE, 2005).



Literature review

Factors affecting duct system efficiency

By decreasing the fluid resistance in the ducting system in the aspect dynamic losses, previous researchers design innovative ideas to optimize the geometric structure of the duct. Rao Gao (2018) proposed a resistance reduction method using a protrusion structure from the perspective of biomimetic structure. The protrusion structure is applied to a tee; the shape of the protrusion is an arc at the tee junction, then centre of the circle is on the centreline of the duct tee, and the width of the arc surface is $4D$. Study on the relationship between traditional tee and tee with protrusion in the aspect of resistance coefficient have been done. Relative to the performance of traditional tee, the resistance of the tee with protrusion was reduced by 36% in main flow direction and 21% in the branch flow.

Before Gao and Li (2018), studies on guide vane inside the duct have been on going with the purpose of reducing drag effect. As early as 1966, investigation on the effect of different guide vane on the resistance of the elbow duct segment has been done by Ito and Imai (1966). His study shows that an optimized guide vane position is not necessarily in the centre of the duct. Haskew (1997) studied the resistance reduction effect of a guide vane on an 80° elbow of a circular duct, it shows that wrong positioning of the guide-vane could substantially increases fluid resistance. However, the method of positioning the guide vane in the elbow is different with the guide vane in the tee and yet study on the subject is scarce. Thus, a number of simulation work was done by Ran Gao (2018) to corelate the reasonable position of the tee guide vane, arc shape optimization of the tee with the guide vane, effects of the flow ratio and the aspect ratio on the resistance reduction rate and analyses of the tee resistance characteristic under different flow velocities and aspect ratios of the duct.

These past studies have showed the advantage of installing guide vanes at sections of the duct system. Coupled with findings made by Gao and Liu (2018) on biomimetic tee design, it is interesting to study the effect of the guide vanes on the improved tee design in terms of its flow behaviour and drag coefficient improvement.

Model description

Design of Wye Tee Duct

In this study, a wye tee duct model is configured to transfer air with the inlet volume flow rate at $0.5 \text{ m}^3/\text{s}$, and both the branch as well as main outlet volume flow rate of $0.25 \text{ m}^3/\text{s}$. The ratio of air flow rate between outlet duct and inlet duct is half. The area for the inlet and outlet is same both for branch and main section. The radius of the duct turning part is also same with the width of the duct. Figure 1 shows the design and important dimension of the wye tee junction used in this study.

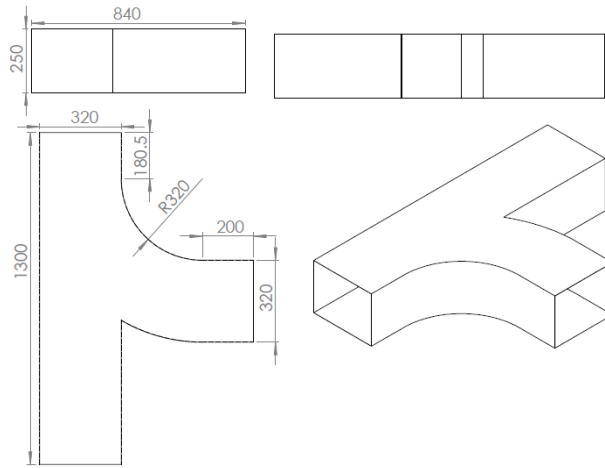


Figure 1: Wye tee duct

Based on ASHRAE (2005), the theoretical resistance coefficient for the branch outlet duct is set at 1.28 and the theoretical resistance coefficient for the main outlet duct is 0.24. A variance of the wye tee duct with protrusion design and guide vane position were designed as shown in figure 2. A number of design variance with different protrusion height at the top of the wye tee duct were first simulated to investigate its effect on friction coefficient. The height of the protrusion is represented in term of ratios; radius of protrusion divide the height of wye tee duct as shown in equation 1. The ratio identified are; $h=0.025$, $h=0.05$, $h=0.075$, $h=0.1$, $h=0.111$, $h=0.125$. Then, the best protrusion ratio identified is installed with a guide vane at multiple position to identify the best position for the vane. The position of guide vane is also determined in term of ratio using equation 2 and the value identified are; $L=0.1$, $L=0.2$, $L=0.3$, $L=0.4$, $L=0.5$, $L=0.6$ and $L=0.7$.

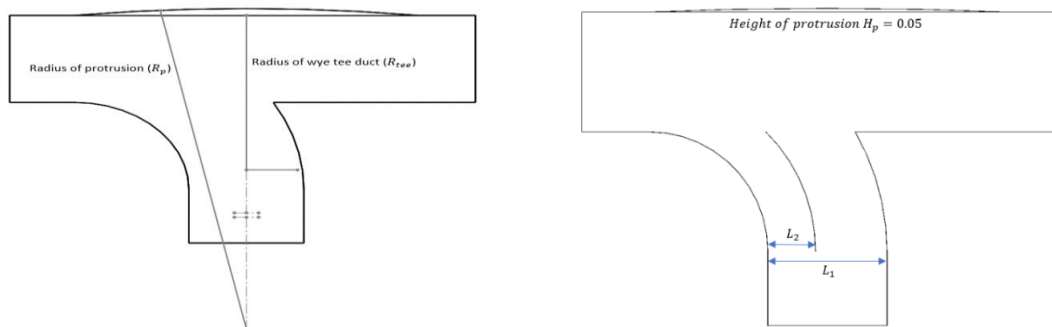


Figure 2: Protrusion ratio, H_p and guide vane location L

$$H_p = \frac{R_{tee}}{R_p} \quad (1)$$

$$L = \frac{L_2}{L_1} \quad (2)$$



Governing equation

The simulation was done using SolidWorks flow simulation. SolidWorks Flow Simulation is a heat transfer and fluid flow analysis software fully integrated into SolidWorks. The software simulate the wye tee duct model in its working fluid environment. The simulation uses the Time-dependent Reynolds-averaged 3D Navier-Stokes equation using the k-e turbulence model. A Flow Simulation consists of Partial Derivative Equation (PDE) which is use to calculate the fluid flow behaviour. The general equation of the PDE is written in equation 3 for reference:

$$A \frac{\partial^2 y}{\partial x^2} + B \frac{\partial^2 y}{\partial x^2} + B \frac{\partial^2 y}{\partial x^2} + C \frac{\partial^2 y}{\partial x^2} + D \frac{\partial^2 y}{\partial x^2} + E \frac{\partial^2 y}{\partial x^2} + E\phi + G = 0 \quad (3)$$

The PED equation is actually sum up of three types of conservation which is conservation of mass, conservation of angular momentum, conservation of energy.

- Conservation of mass

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial t_j} (pu_i) = 0 \quad (4)$$

- Conservation of angular momentum

$$\frac{\partial(pu_i)}{\partial t} + \frac{\partial}{\partial t_j} (pu_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j} (\tau_{ij} \tau_{ij}^R) + S_i \quad i = 1,2,3 \quad (5)$$

- Conservation of energy

$$\frac{\partial p_H}{\partial t} + \frac{\partial p u_i H}{\partial x_i} = \frac{\partial}{\partial x_i} (u_j (\tau_{ij} \tau_{ij}^R) q_i) + \frac{\partial p}{\partial t} - \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + p\epsilon + S_i u_i + Q_H \quad (6)$$

Grid independence test

Grid independence test was done to find out the optimum mesh density to be used in the computational work. There are five levels of mesh density used as shown as shown in table 1.

Table 1: Mesh density

	Level 1	Level 2	Level 3	Level 4	Level 5
Total Cell	3104	23030	142844	172514	176384
Fluid Cell	3104	23030	142844	172514	176384
Solid Cell	2320	12118	64182	64102	66132
Partial Cell	1796	7830	31434	31274	33044

The simulation was run and results were expressed in resistant coefficient as shown in figure 3. It shows that grid independence was achieved at level 4. Thus, subsequent simulation works were done using level 4 mesh density.

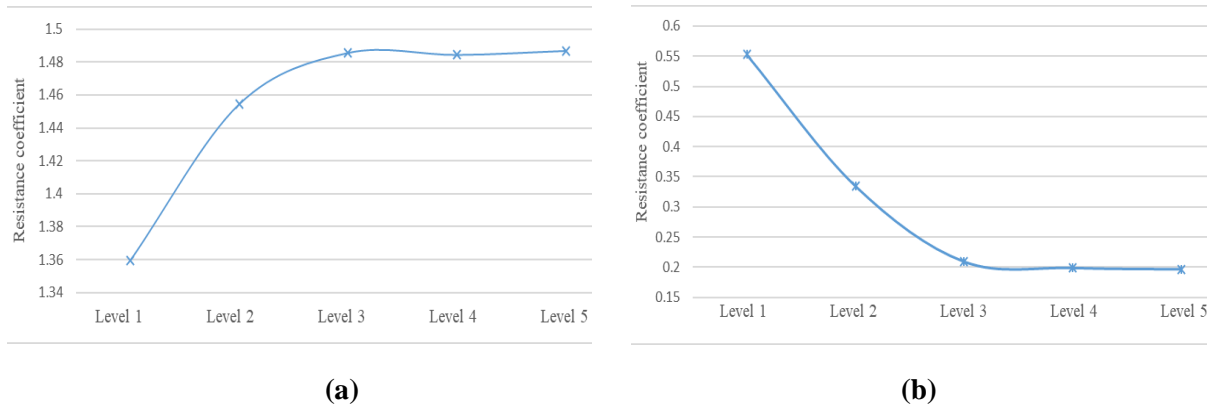


Figure 2: Mesh density vs Resistance coefficient, (a) C_b and (b) C_s

Result and discussion

Effect of protrusion ratio on resistance coefficient

Simulation work on multiple protrusion ratio were done and the corresponding resistance coefficient were calculated both at the main and section branch as shown in figure 3. The best protrusion ratio is, $H_p = 0.05$ while the worst protrusion height is 0.1. The original duct simulation calculated the resistance coefficient in the main section as 0.19663 while the best protrusion duct with protrusion height 0.05, yield 0.178. These results show an increase of efficiency by 9.47%. Meanwhile, the resistance coefficient in the branch section is 1.48692 for the original duct while the 0.05 protrusion duct resistance coefficient is calculated at 1.477. The efficiency of the air flow rate was increased by 0.67%.

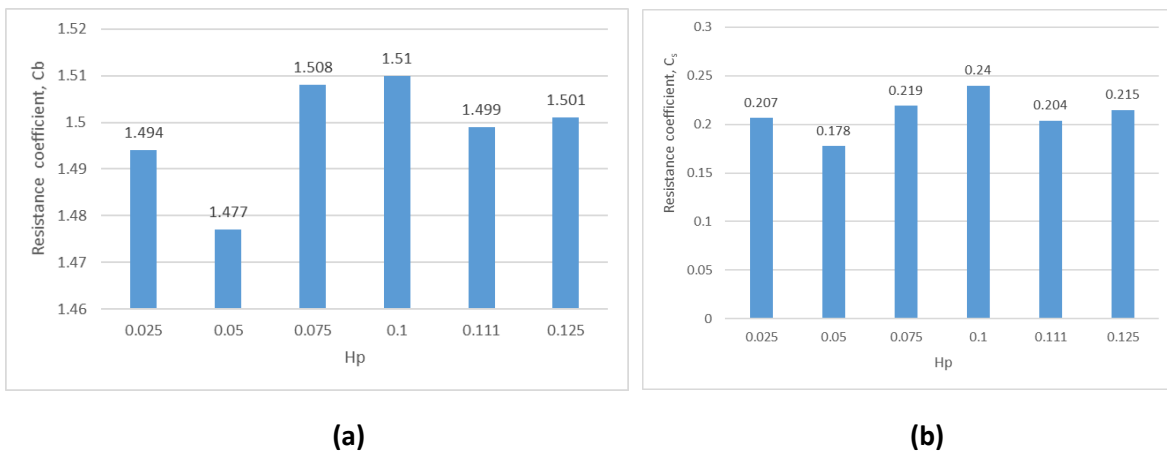


Figure 3: Height of protrusion H_p VS resistance coefficient, C_b and C_s

The air flow velocity at the top part of the duct will decrease when the air flow passes through the tee section, which means air velocity was dissipated. For the standard wye tee duct, there is an air velocity lost observe which is represented by the yellow colour gradient. A wye tee duct with protrusion however shows better flow with lesser air velocity dissipation along the upper wall. The maximum velocity for the original wye tee duct is 6.928 m/s and minimum velocity is 0.378m/s. Whereas, the maximum velocity for the protrusion tee duct is 6.970 m/s and minimum velocity is 0.470m/s. These result shows that both maximum and minimum velocity were increased in protrusion wye tee duct thanx to the protrusion design.

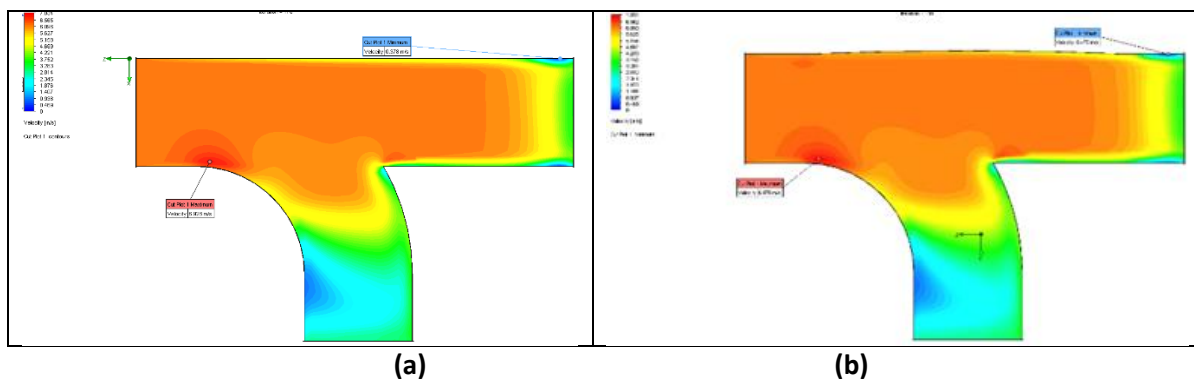


Figure 4: Air velocity variance in a) Standard wye tee and (b) Wye tee + protrusion design

With the best protrusion ratio identified at $H_p = 0.05$, the following simulation were done by positioning the guide vane at different branch duct ratio. Calculated resistance coefficient shows that the best guide vane position for the branch section is 0.1 with resistance coefficient 1.4314. However, another guide vane position for the main section is 0.3 which resistance coefficient 0.1528. In this research, the best guide vane position is $L=0.3$ based on the overall aspect. The guide vane position $L=0.3$ have the lowest resistance coefficient for the main section which is 0.1528 and have good resistance coefficient for the branch duct section which is 1.4512. For the main section, the efficiency of the air flow rate was increased by 22.29% when compared with the original wye tee duct. Thus, the optimize guide vane position compared with the standard wye tee duct decrease the resistance coefficient from 0.19663 to 0.1528 and the efficiency of air flow rate was increased by 22.29%. Meanwhile, the efficiency of the air flow rate was increased by 2.40% for the branch section compared with the standard wye tee duct. In the branch section, the optimize guide vane position on a standard wye tee duct decrease the resistance coefficient from 1.48692 to 1.4512 and the efficiency of air flow rate was increased by 2.40%.

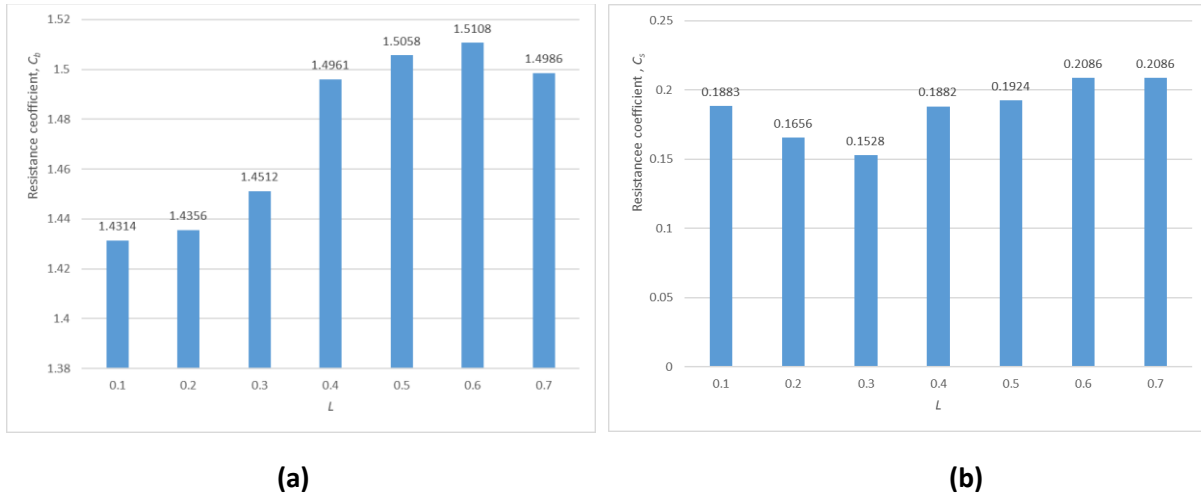


Figure 5: Guide vane position, L VS resistance coefficient; (a) C_b and (b) C_s

Comparing the air velocity gradient between the standard wye tee duct and the protrusion with guide vane duct shows better air flow and lesser air velocity dissipation as shown in figure 6. The guide vane also improves the air flow homogeneity at the outlet of the branch duct reducing the effect of excessive friction at the duct wall and reducing the overall friction coefficient.

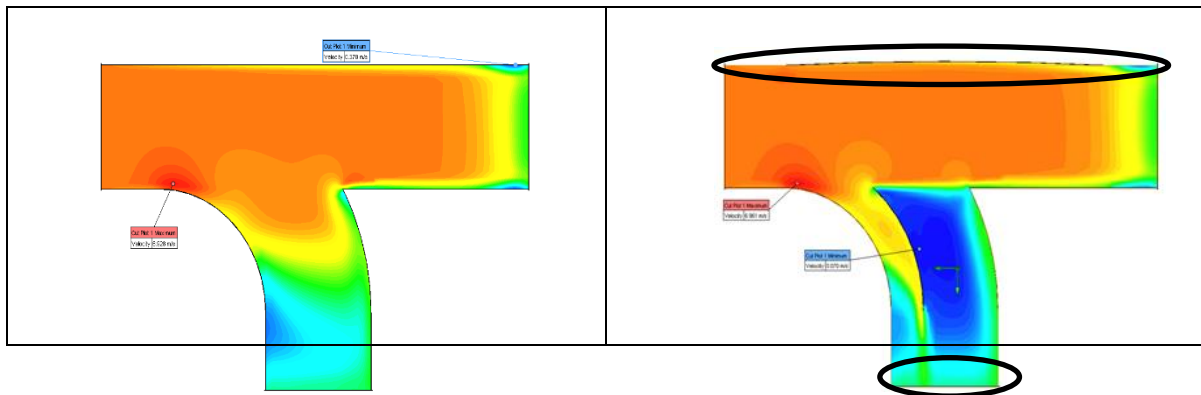


Figure 6: Air velocity variance in a traditional wye tee and wye tee + protrusion + guide vane at optimum location

Conclusion

As a conclusion, this study has shown thru simulation work that the resistance coefficient in a wye tee duct design can be improved by adding a protrusion design coupled with a guide vane position at the branch section of the duct. Simulation work at different duct position reveals that at a constant designated flow rate, there exist and optimum location that reduces resistance coefficients. In the current work, it is found that positioning the guide vane at $L = 0.3$ yields an



increase of 22.9% at the main duct and 2.4% in the branch duct compared to a traditional wye tee duct design.

Acknowledgements

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SIX-FOLD D-SHAPED SURFACE PLASMON RESONANCE BASED PHOTONIC CRYSTAL FIBRE SENSOR

Abdosllam M. Abobaker¹,
Suoda Chu²
K. Nakkeeran²
Sumeet S. Aphale²
P. Ramesh Babu³
and K. Senthilnathan³

¹ Department of Communications Engineering, College of Electronic Technology, Bani Walid, Libya

² School of Engineering, Fraser Noble Building, University of Aberdeen, Aberdeen AB24 3UE, UK

³ Photonics Research Laboratory, School of Advanced Sciences, VIT University, Vellore-632 014, Tamil Nadu, India

Abstract: *In work, we design a 6-fold D-shaped photonic crystal fibre based surface plasmon resonance sensor in detail. The numerical results obtained from the finite element method simulations reveal the coupling relations between fundamental core mode and three surface plasmonic modes which have different electric field distributions for analytes with different refractive index (RI). Two different types of SPRs, namely, 'dielectric like' resonance with low-loss peak and 'plasmon like' resonance with high-loss peak, are also found through a critical analysis on the electric field distribution evolutions of the fibre modes. In order to reduce the negative influence from the sub-peak of the secondary SPR on the sensor's dynamic sensing range (DSR), we found that by adjusting the liquid analyte layer/analyte binding layer thickness from thick layer (1500 nm) to thin layer (500 nm), the DSR can be extended by a ratio of 44.4% from 1.33-1.41 to 1.33-1.45 at the cost of a reduced maximum sensitivity from 7900 nm/RIU to 5300 nm/RIU. Owing to the simple structure design of the proposed sensor, we envisage that this highly sensitive D-shaped PCF-SPR sensor could be developed as a versatile and competitive instrument with a large and flexible refractive index detection range.*

Keywords: *D-shaped, Sensor, Photonic crystal Fibre, Refractive Index Sensor, Sensitivity, Surface Plasmon Resonance.*

Introduction

The sensing applications based on the optical excitation and detection of the surface plasmon resonance (SPR) phenomenon have been widely studied. The fibre sensors based on SPR are proven to be a commercial-successful technology in the field of medical diagnosis, chemical detection, bio-chemical reaction test/recognition, food safety control, environment monitoring, etc. The high sensitivity to the change of refractive index of the medium in contact with the surface of thin metal film (typically gold or silver with dielectric), has been widely utilized for those sensing applications [1-3].

The SPR phenomenon is generally defined as the strong coupling between the electromagnetic wave and surface plasmon wave at the interface of dielectric and metal [4]. Then optical fibre was introduced as the dielectric medium to overcome the traditional configuration's drawbacks. Due to its design flexibility and compact in size [5], the metal coated optical fibres, as

an idea alternative to the prism, have been utilized to form the excitation of surface plasmons [6-8]. Therefore, low-cost, highly integrable, miniaturization and portable optical fibre based SPR sensors have been achieved. Recently, photonic crystal fibre (PCF) is widely used as a novel class of optical fibre for different sensing purposes. The PCF-SPR based sensors are now widely studied because of their simple and compact probe designed for high sensitivity, highly robust, low-cost, fast response, label-free detection [9]. Moreover, by optimizing the structural parameters like air holes diameters, the distance between two adjacent air holes, it is possible to enhance the sensitivity and the sensing range. The hexagonal D-shaped PCF is one of the most frequently used fibre media for common PCF-SPR sensor applications. In this paper, we numerically investigate the sensing performance of a standard 6-fold hexagonal D-shaped PCF-SPR sensor on a large analyte refractive index range from 1.33 to 1.48. A comprehensive numerical analysis based on the finite element method (FEM) is adopted.

Geometrical Structure and Numerical Analysis

The schematic of the proposed biosensor is shown in Fig. 1. It comprises of four layers of air holes arranged in a six-fold hexagonal PCF structure of air holes diameter of $d=1.2\ \mu\text{m}$ with a solid core. The distance between two holes (pitch), λ , is $2.5\ \mu\text{m}$ and the radius of the whole sensor is set as $11\ \mu\text{m}$. An open D-shaped analyte channel is designed at the top part of the fibre cross-section so that the analyte can be infused in the channel. The height of the D-shaped channel, d_a , is $8\ \mu\text{m}$. A uniform nano-scale gold metal film is deposited on the flat side-polished surface with its layer thickness of $t_{\text{Au}}=45\ \text{nm}$ for surface plasmon polaritons generation. The liquid analyte layer thickness in the D-shaped channel is considered as $1500\ \text{nm}$.

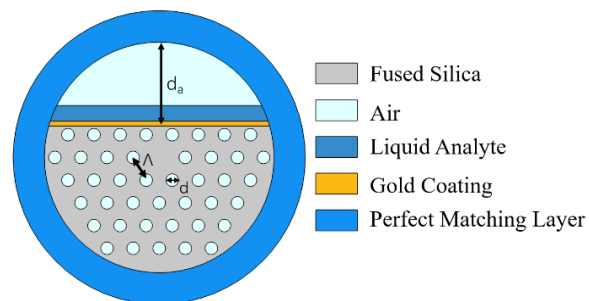


Figure 1: Cross-section of the proposed six-fold PCF-LSPR sensor.

Analysis of Modes

It is well known that the surface plasmon mode (PM) is generated and coupled with the main core-guided fundamental mode (FM) at particular resonant wavelength [10]. In other words, it means that there is a light energy transfer between those two modes. At the resonance wavelength, the loss spectra of the majority of fibre-based SPR sensors exhibit single-resonance-peak characteristic with a sharp and deep resonance peak [11].

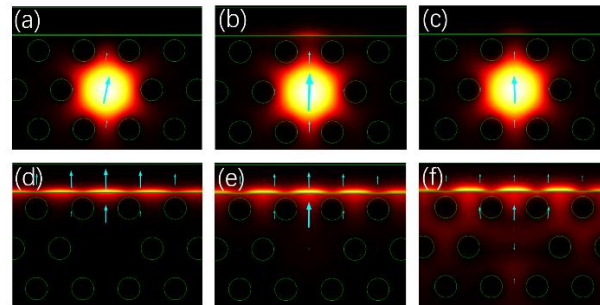


Figure 2: Light distributions in the cross-section of D-shaped PCF-SPR sensor for different wavelengths for the analyte RI of $n_a=1.38$. (a) and (d) are the FM and PM at 600 nm (shorter wavelength with respect to the resonance). (b) and (e) are the FM and PM at resonant wavelength of 690 nm. (c) and (f) are the FM and PM at 770 nm (longer wavelength with respect to the resonance). The arrows indicate the direction of the electric field

The formation of the PM is shown in Figs. 2. The refractive index of the liquid analyte is considered as $n_a=1.38$. Figures 2 illustrate both the distribution of the light energy flow of the FM [Figs. 2 (a), 2 (b) and 2 (c)] and the PM [Figs. 2 (d), 2 (e) and 2 (f)] of the proposed sensor at 600 nm. Here, the arrows indicate the direction of the electric field. Figures 2 (d), 2 (e) and 2 (f) show the formation of the PM for all three wavelengths, viz., shorter, equal and longer with respect to the resonant wavelength. In Figs. 2 (b), a weak surface plasmon resonance can be observed at the inference between the thin gold film and the dielectric (optical fibre). From Figs. 2 (a) to 2 (c), it is clear to show a full process of SPR.

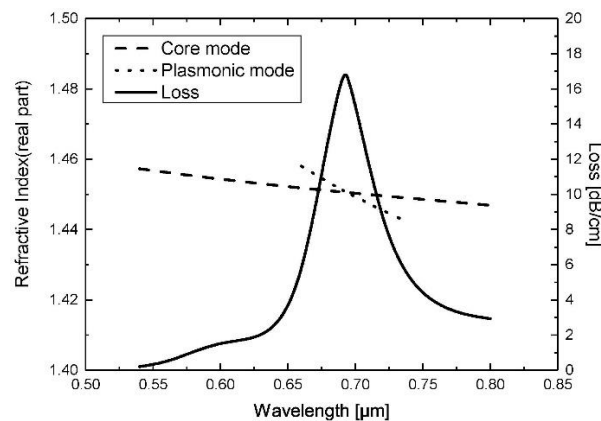


Figure 3: The confinement loss, dispersion relations of FM and PM of the D-shaped hexagonal PCF-SPR sensor for an analyte RI of 1.38.

Figure 3 shows the confinement loss spectrum (solid curve), dispersion relations of the FM (dashed curve) and PM (dot-dashed curve) for the D-shaped hexagonal PCF-SPR sensor when the RI of an analyte is 1.38. As it is illustrated in Fig. 3, a sharp and deep single resonance peak has been obtained by proposed sensor for $n_a=1.38$ at the resonance wavelength of 690 nm.

However, for higher refractive index analyte range of 1.46, two resonance peaks are found in the confinement loss spectrum at their resonance wavelengths of 1337.5 nm and 1515 nm as shown in Fig. 4.

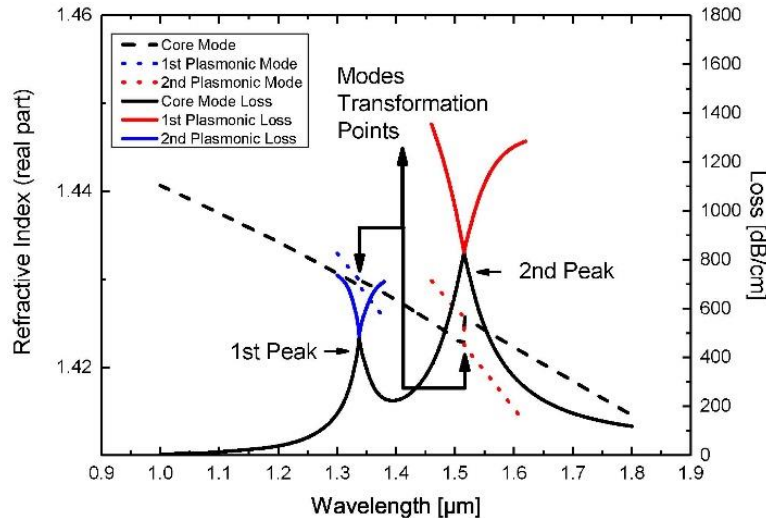
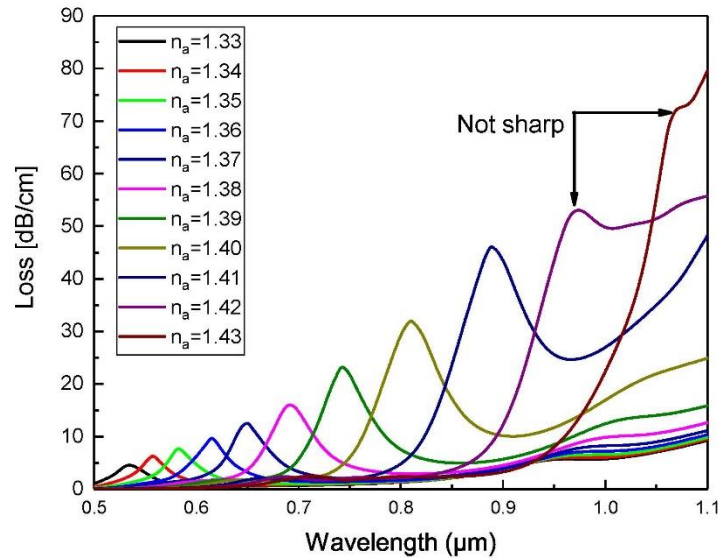


Figure 4: The confinement loss, dispersion relations of FM and PM of the D-shaped hexagonal PCF-SPR sensor for analyte RI $n_a=1.46$.

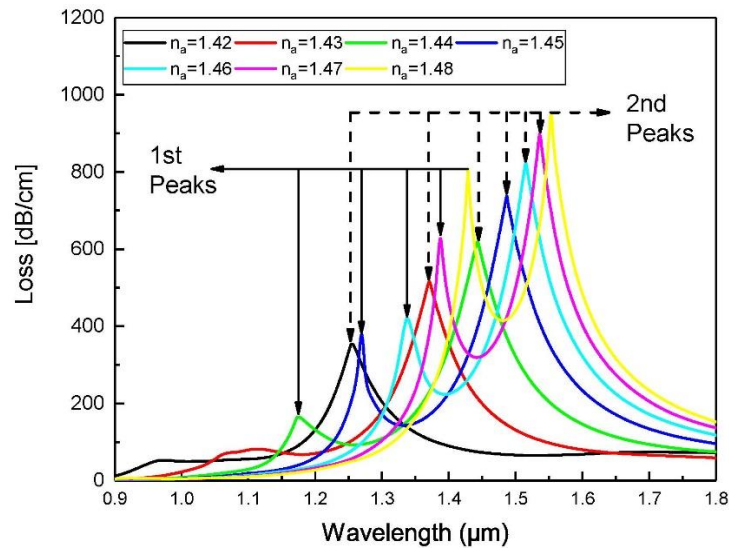
For a large range of analyte RI, there are two different types of SPRs for the proposed D-shaped hexagonal PCF-SPR sensor, the 'dielectric-like' SPR and the 'plasmon-like' SPR, respectively. In literature, they are also named as 'incomplete coupling' and 'complete coupling' [12-14]. Therefore, the phase matching conditions for them are found to be different with each other as well. For lower RI of analyte, as its resonance wavelength is usually located at shorter wavelength region, the 'dielectric-like' SPR will occur with the phase matching condition of the equality between the real parts of effective refractive indices (n_{eff}) for FM and the PM at upper boundary of gold film surface. On the other hand, for higher RI analytes, as their resonance wavelengths are usually located at longer wavelength region, the 'plasmon-like' SPR will occur at the surface of gold film.

Sensing Performance

In the sensing process, to obtain a better performance of a refractive index based SPR fibre sensor, the energy transferred to the PM is required to be extremely sensitive to the RI changes of the aqueous analyte [15]. When there are small RI changes in the analyte due to chemical/biochemical interactions, the real part of the n_{eff} of the PM should shift its position with respect to the light signal wavelength. As a consequence, the resonant wavelength occurring at the phase matching condition will also have a significant shift accordingly.



(a)



(b)

Figure 5: The loss spectra for the analyte refractive index (n_a) varying from (a) 1.33 to 1.43 in steps of 0.01 and (b) 1.42 to 1.48 in steps of 0.01.

From Figs. 5 (a), we can observe only one single resonance peak for analyte RI ranges from 1.33 to 1.41 within the wavelength range from 0.5 μm to 1.0 μm . Here, the confinement loss increases as the RI of the analyte is increased. It should be noted that, due to the increasing high loss of the designed fibre and the existence of a secondary SPR caused by FM and hybrid PM in the longer wavelength, the loss peaks for RI=1.42 and 1.43 become more and more blunt and broad. As a result, the resonance peak can hardly be obtained and observed by using a spectrometer. Then, Fig. 5 (b) shows the trend for the family of the confinement loss curves of the



analyte's RI in the range of 1.42 to 1.48 with dual resonance peaks in the wavelength bandwidth of 0.9 μm from 0.9 μm to 1.8 μm . Due to the existence of SPR between fundamental core mode and hybrid surface plasmon, a sub-peak is observed from the confinement loss spectra. As the secondary SPR always occurs at the longer wavelength, it is a 'plasmon-like' SPR with very high loss. In practical, because of the limitation on observation bandwidth of an optical spectrometer, we highly expect there would be only one single resonant peak for one analyte RI value. Therefore, in the detection process, dual-peaks characteristic will cause errors in the measurement within the certain sensing bandwidth. It is clear that the uniqueness and accuracy of single peak measurement cannot be guaranteed by the proposed sensor for RI of any analyte higher than 1.41 due to the overlap of two resonance peaks. This drawback limits the proposed sensor's detection range and sensing performance.

By introducing the wavelength interrogation method, the sensitivity of the sensor can be calculated in nm/RIU. For example, in Fig. 5 (a), the wavelength shift between the confinement loss peaks for RI 1.40 and 1.41 is 79 nm. Hence, the sensitivity of the PCF-SPR sensor for the analyte RI change from 1.40 to 1.41 is calculated as 7900 nm/RIU.

Conclusion

In this paper, we have investigated a common D-shaped hexagonal photonic crystal for larger refractive index detection range. The numerical results show that the proposed sensor could achieve a maximum sensitivity of 7900 nm/RIU (RI =1.33 to 1.41), 5300 nm/RIU (RI =1.33 to 1.45) with thick analyte binding layer of 1500 nm and thin analyte binding layer of 500 nm, respectively. From the simulation results, we have observed that two different types of SPRs named as 'dielectric-like' SPR with low loss and 'plasmon-like' SPR with high loss. As the D-shaped hexagonal PCF-SPR sensor is one of the most promising and fabricable SPR sensors, we believe that it could be a potential sensing device for large range of analyte refractive index detection.

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PREVALENCE OF TREATMENT ADHERENCE AMONG ATTENDANCE AT HEMODIALYSIS IN MMAKAH

GHANIM HAMID AL-KHATTABI¹

¹Department of Community Medicine and Epidemiology, Directorate of Public health, Ministry of Health, Makkah, Saudi Arabia, Email: (dralkhattabi@gmail.com)

Abstract: Background: There are remarkable paucity in the studies which identify prevalence of adherence and non-adherence risk factors in hemodialysis patients in Saudi Arabia. Despite the importance of this issue, there are very limited studies which discuss our topic in Saudi Arabia. **Aims & Objective:** To identify the prevalence of adherence to (hemodialysis attendance, medications, fluid restrictions, and diet restrictions) among hemodialysis patients at governmental kidney centers in Makkah city in Saudi Arabia in the year 2013. **Materials and Methods:** Based on a cross section study design, a sample of 361 hemodialysis patients were selected randomly (stratified random sample) from the list of available patients in three hemodialysis centers at three major governmental hospitals in Makkah city, and they were invited to be enrolled in the study after taking their consent. Clinical measures and a valid, reliable Questionnaire (ESRD-AQ) were used to assess adherence of patients to (hemodialysis attendance, medications, fluid restrictions, and diet restrictions). **Results:** The prevalence of hemodialysis patients' adherence to Dietary, fluid restrictions recommendations and medication prescription were 88.37%, 87.78% and 87.99%, respectively and nearly half of patients were adherent to dialysis sessions (55.96%). The highest adherence rate was for diet restriction (88.37%) and the lowest was for attendance to dialysis sessions (55.96%). **Conclusion:** The overall adherence rates in our study population were thought to be within the range of most published international studies.

Key Words: Prevalence, Hemodialysis, Adherence, Treatment, Saudi Arabia.

Introduction

Adherence can be defined as: following medical or health advice (Denhaerynck et al., 2007)[1] or "the extent to which a person's behaviour corresponds with the agreed recommendations of a healthcare provider in terms of taking medicines, following the recommended diet and/or executing lifestyle changes[2]. End-stage renal disease (ESRD) is defined as irreversible decline in kidney function, when renal replacement therapy (RRT) is needed for survival of patients. There are two major types of renal replacement therapy, which include dialysis and kidney transplantation.[3]

Despite the importance of our topic there are remarkable paucity in the studies which identify prevalence of adherence in hemodialysis patients in Saudi Arabia. According to the researchers' extensive research, there are very limited studies which discuss our topic in Saudi Arabia.

The first dialysis session in Saudi Arabia took place in 1971 and the first renal transplant in 1979.[4] In Saudi Arabia, there is consistent increase in prevalence and in the incidence of newly-diagnosed individuals with end-stage renal disease (ESRD), especially over the last 3 decades, this rise exceed those reported from many countries. Those patients requires renal replacement therapy in each year, fuelled by the large expansion of the aged population as well as the rapid emergence of diabetic nephropathy disease.[5]



The increase in the number of dialysis patients has been seen in virtually all countries; the annual increase in dialysis patients has been around 8%. In the KSA, the incidence and prevalence of dialysis patients have 10-15 fold increase when compared to 1983.^[6] The incidence of chronic renal disease is 260 per one million of world population and increases 6% annually.^[7] The dialysis statistics performed by the Saudi Center for Organ Transplantation (SCOT) at the end of year 2012 showed there were a total of 14,171 patients were on dialysis, 12,844 of them were treated by hemodialysis (HD) and the remaining 1,327 by peritoneal dialysis (PD).^[8] The prevalence of end stage renal failure treated by dialysis was estimated to be 499 cases/PMP (per million populations). Total death was 1638 (11.6%), while the incidence of treated ESRD was estimated at 129 cases/PMP. However, the incidence of end-stage renal disease (ESRD) in Saudi Arabia is not well documented; The few reports that exist are either single hospital studies or retrospective data from limited areas or age-groups.^[9-14]

Literature review

In view of the rapidly increased of ESRD in Saudi Arabia, there is a need to determine the adherence rate to therapeutic regimen among patients undergoing hemodialysis. Data on adherence to treatment regimens (fluid, dietary, medication and dialysis attendance) is however not available. Furthermore, medical staff services in HD centers in Saudi Arabia are generally focused on physical care. Holistic care is either not performed or is inadequate.

The majority of patients use center-based hemodialysis as treatment modality thus offering a unique opportunity to examine adherence behaviour in this population. Hemodialysis patients are asked to adhere to a very difficult treatment regimens consisting of fluid and diet restrictions, several daily medications, and, mostly, 3- or 4- hour hemodialysis sessions three times in each week. Most of hemodialysis patients fail to adhere to their recommended treatment. Even though these regimens are difficult, it is necessary for patients to adhere to their prescribed regimens for optimal health and well-being.^[15] Poor adherence to complex multimodal therapies is a widely recognized problem in the daily care of hemodialysis patients, which contribute to excess morbidity and mortality of this population.^[16] There is evidence that good adherence to the treatment can reduce hospitalization risk in HD patients.^[17] There is solid evidence that adherence of ESRD patients' correlates with morbidity and mortality.^[18] Specifically, skipping treatment and poor dietary adherence are strongly associated with greater risk for death.^[19]

Treatment adherence of patients on maintenance hemodialysis, which is the most common therapy [renal replacement therapy (RRT)](United States Renal Data System [USRDS], 2009^[20]; the Saudi Center for Organ Transplantation data, 2012^[8] usually consists of four components, which include attendance at hemodialysis sessions, adherence to the recommended medications, and fluid and diet restrictions.

The current study aimed at assessing the prevalence of adherence to (hemodialysis attendance, medications, fluid restrictions, and diet restrictions) among hemodialysis patients at governmental kidney centers in Makah city in Saudi Arabia in the year 2013.



Materials and Methods

This cross-sectional study was conducted in three hemodialysis (HD) centers at three major governmental hospitals in Makah city. It is located at the Western Region of the Kingdom of Saudi Arabia and it is the capital of Makah Province. According to the preliminary results of the population and housing census taken on 2010, the total population of Makah city was roughly 1.6 million.[21] The population got their health care services through governmental and private health facilities. There are 8 governmental hospitals and many other private hospitals and private polyclinic. Our registered patients are in three HD centers in three major governmental hospitals in Makah city are estimated to be around 2000.

The study population of the cases included all patients with ESRD requiring MHD. These patients were registered in the hemodialysis unit of kidney centers. The centers accommodate for patients infected by HCV, HBV and HIV. Patients who are HBV and HIV positive are kept in isolated wards during treatment. The HD machines are kept busy through the year with four shifts daily. Sometimes a fifth shift has to be arranged to overcome the heavy workload as usual, there is a large influx of patients during the Holy months of Ramadan and Hajj due to a large number of visitors from outside the city of Makah and there is an arrangement for visitors who have ESRD and need dialysis to do it in governmental hospitals. Small HD units are also available in other governmental and private hospitals, which accommodate for only a small percentage of patients.

Inclusion criteria were any adult patients above 18 year, conscious, understand, able to give an informed consent and regular on hemodialysis. Individuals who agreed to participate and met the eligibility criteria were included in the study. Patients on peritoneal dialysis were excluded.

The sample size was calculated by using Epi-Info program version 6.04. There are around 2000 patients (population size) in hemodialysis centers in Makah city and the estimated proportion for prevalence of adherence from literature was about 50%, so the required sample size was 385 patients, with 95% CI and allowable error of 5%. Using the single proportion equation for dichotomous variables: $[N = Z^2 \times P(1-P) / C^2]$ Where, N= Sample size; P = Percentage of population; C = Confidence level; Z = Z-Value (e.g., 1.96 for a 95 percent confidence level). Accordingly, the estimated sample size was 385. Patients who responded and participated in our study were 361. So, our response rate was $361/385=93.8\%$. The sample was selected through stratified random sampling approach to obtain an equal number of male and female patients.

The available (770) patients at the HD centers in our three hospitals undergo HD for an average of 3 times a week, with a small percentage undergoing hemodialysis only twice a week. The hemodialysis sessions take place in four shifts. The researchers comprised the study group, which included 361 patients through stratified random sample from the list of available patients at each HD center in each hospital. This method of sample collection allowed the researcher to cover patients from all the wards, including male and female wards, the isolation section, both hepatitis C positive and negative patients and at different times of the day.

We took our sample from each hospital according to proportion of available patients present in each hospital. We take half of available patients present in each hospital. The sample selected from each hospital through stratified random sample approach according to gender from the available patients` list to obtain an equal number of male and female patients. We take a list of male patients and through systematic random sample we select our sample. And we take a list of female patients and through a systematic random sample we select our sample. Adherence to treatment regimens in patients with ESRD was measured by a variety of methods, with no one



method being superior.[1,15,22] Questionnaire (ESRD-AQ) and clinical measures were used to evaluate treatment adherence or non-adherence in patients with ESRD on maintenance HD (Hemodialysis).

Clinical Measures:

Each patient's adherence behaviours were rated by the researcher based on IDWGs, dialysis attendance, serum potassium and phosphorous levels over the last month. These criteria were used separately to distinguish between adherer and non-adherer.[17] Dry weight (weight at the end of dialysis treatment) in dialyzed patient is the lowest weight which patient can tolerate at the end of dialysis treatment without the development of symptoms or hypotension.[23] Inter Dialytic Weight Gain (IDWG) is calculated as the difference between the patient's weight obtained at the onset of a dialysis treatment and the weight obtained at the end of the previous dialysis.[24-26]

Questionnaire:

The End-Stage Renal Disease-Adherence Questionnaire (ESRD-AQ) for patients requiring in-center HD was used to measure treatment adherence behaviours in four dimensions: HD attendance, medication use, fluid restrictions, and diet restrictions.[27,28] The ESRD-AQ instrument is a self-administrated questionnaire consist of 46-item, completion of the instrument took approximately 20 to 40 minutes.[27,28] The ESRD-AQ is the first self-report instrument to address all components of adherence behaviours of patients with ESRD. The findings support that the instrument is reliable and valid, and is easy to administer.[27,28]

The original English version of questionnaire was translated to Arabic then the Arabic version was back translated to English and the English version was compared with the original English version to see if they were identical, if they were not identical, they were translated again till they become identical and to ensure lexical equivalence. However, it was subjected to validity testing after being translated into Arabic language by consultant of family medicine, consultant of community medicine and nephrology consultant.

The End-Stage Renal Disease-Adherence Questionnaire (ESRD-AQ) for patients requiring in-center HD was designed to measure treatment adherence behaviours in four dimensions: HD attendance, medication use, fluid restrictions, and diet restrictions recommendations. The final version of the ESRD-AQ consists of 46 questions/items divided into five sections. The first section pursues general information about patients' ESRD and RRT related history (5 items), and the remaining four sections ask about treatment adherence to HD treatment (14 items), medications (9 items), fluid restrictions (10 items), and diet restrictions recommendations (8 items). Responses to the ESRD-AQ utilize a combination of Likert scales and multiple choice, as well as "yes/no" answer format. The adherence behaviour subscale was scored by summing the responses to questions 14, 17, 18, 26, and 46. The weighting system for scores was determined based on the degree of importance relevant to clinical outcome of each dimension. The attitude/perception subscale was scored by summing the responses to questions 11, 12, 22, 23, 32, 33, 41, and 42. The remaining questions obtain information about patients' ESRD and RRT related history. The ESRD-AQ was designed such that higher scores indicate better adherence.[27]



Pilot Study

A pilot study was carried out in Jeddah kidney center at King Fahd general hospital (referral center for HD patients in western province) on about 10% of our sample size who were not included in the main study. The aim of the pilot trail was to test for clarity and feasibility of the tools, it also helped to estimate the time needed for filling the questionnaire, taking clinical measures and conducting the health educational program, re-evaluate the intervention process, re-evaluate tools of the study (the questionnaire and clinical measures), gain an idea of the cost required, and to identify any problems that may be encountered during the study so that solution could be promptly found.

Statistical Analysis

All data were coded and entered in a personal computer. Under supervision of an expert biostatistician. Statistical analysis was performed using Statistical Package for Social Science (SPSS) program, version 16. The data was checked and corrected for errors at the stages of coding and data entry and quality control was ensured. Initially, the frequency distribution and simple descriptive statistical analysis and percentages for qualitative variables and mean, median and range for quantitative variables were done for the study population.

Results:

As shown in table 3, the mean age of subjects was 50.05 ± 15.81 years old; range between (14 to 95 years). About half of patients (47.6%) were males. The majority of patients were Saudis (93.9%). About two-third of patients (67.3%) were form Al-Noor Specialist hospital (ANSH), 20.8% from King Abdul-Aziz hospital (KAH) and 11.9% from King Faisal hospital (KFH). About two-third of patients were married (62.3%). About half of patients (44%) had secondary school and above. The mean duration of dialysis was 74.83 ± 64.43 months range between (2 to 336 months) and half of them (50.3%) did their dialysis for 60 months or greater, compared to (21.2%) between 13 to 36 months, (15.9%) for 12 months or less and (12.6%) between 37 to 60 months. The mean inter-dialytic weight gain was 2.24 ± 1.11 kg; range between (0 to 6.500 kg).

The mean number of daily tablet(s) taken by patients was 6.09 ± 3.710 ; range between (1 to 26). The presence of comorbidities was common in this sample, the mean number of co-morbid disease was 3.04 ± 1.7 ; range between (0 to 10) disease(s). Unknown cause (32.4%), hypertension (23.0%), diabetes mellitus (21.9%), glomerulonephritis (3.6%) were the four major etiology of renal failure; other (19.1%) of cases were caused by other causes. Most of patients (93.6%) did not had a prior kidney transplant history, compared to (6.4%) had a prior kidney transplant history. Half of patients (49.9%) had hepatitis c virus (HCV) disease, compared to (50.1%) did not had that disease. Most of patients (93.9%) were diagnosed with HTN. About (39.6%) of patients were diagnosed with DM. Only 10.2% of patients had a psychiatric disease.



Table-1: Explanation for our study population

Hospital	Registered Patients	Available Patients	Required Sample	Response Sample
ANSH	1346	518	259	243
KAH	416	162	81	75
KFH	238	90	45	43
Total	2000	770	385	361

Table-2: Explanation of sampling technique for stratified sample

	ANSH		KAH		KFH	
Available patients:	518		162		90	
Gender	Male	Female	Male	Female	Male	Female
Available patient:	266	252	74	88	28	62
Required sample	133	126	37	44	14	31
Response Sample	125	118	34	41	13	30

Table-3: Socio-demographic and clinical characteristics of the study group (n=361)

Characteristics	%	
Age (years)	< 65 years	78.9
	> 65 years	21.1
	Mean (SD)	50.05 (15.81)
Gender	Male	47.6
	Female	52.4
Marital status	Married	62.3
	Single	21.3
	Others (divorced, widowed)	16.3
Education	Illiteracy	31.3
	Primary school	24.7
	≥ Secondary school	44
Causes of kidney failure	Diabetes mellitus	21.9
	Hypertension	23
	Glomerulonephritis	3.6
	Others	19.1
	Unknown	32.4
Duration of Dialysis (months)	12 months or less	15.9
	13 to 36 months	21.2
	37 to 60 months	12.6
	60 months or greater	50.3
	Mean (SD)	74.83 (64.43)
Interdialytic weight gain (kg)	Range	2-336
	Mean (SD)	2.24(1.11)
Patients hospital	Range	0-6.500
	ANSH	67.3
	KAH	20.8
Presence of co-morbid disease	KFH	11.9
	Yes	99.2
Number of co-morbid disease	No	0.8
	Mean (SD)	3.04 (1.7)
	Range	0-10
Daily tablet(s)	Mean (SD)	6.09 (3.71)
	Range	1-26
Kidney transplant history	Yes	6.4
	No	93.6
HCV	Yes	49.9
	No	50.1
HTN	Yes	93.9
	No	6.1
D.M	Yes	39.6
	No	60.4



Hospitalization history	Yes	77
	No	23
Pre-hemodialysis Serum potassium (mmol/L)	Mean (SD)	5.10 (0.91)
	Range	2.70 – 10.20
Pre-hemodialysis Serum phosphorus (mg/dl)	Mean (SD)	5.33 (1.76)
	Range	1.30 – 11.60
Psychiatric disease(s)	No	89.8
	Yes	10.2

Table-4: Prevalence of adherence behaviour (n=361)

<u>Adherence behaviour indicator</u>	<u>Clinically determined adherence rates</u>
Dietary	88.37% ¹
Fluid	87.78% ²
Medications	87.99% ³
Attendance to dialysis	55.96% ⁴

1-Serum potassium achieved adherence criteria;

2-IDWG achieved adherence criteria;

3-Serum phosphorus achieved adherence criteria;

4-Subjects skipped at least one dialysis session (data derived from dialysis record).

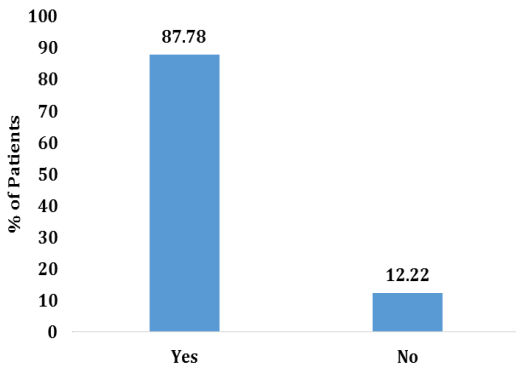


Figure-2: Adherence to diet restriction recommendations among the study group

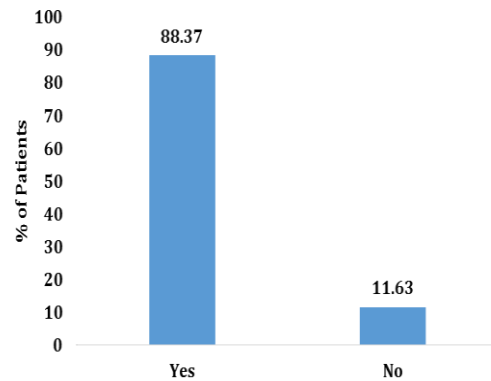


Figure-1: Adherence to fluid restrictions recommendations among the study group

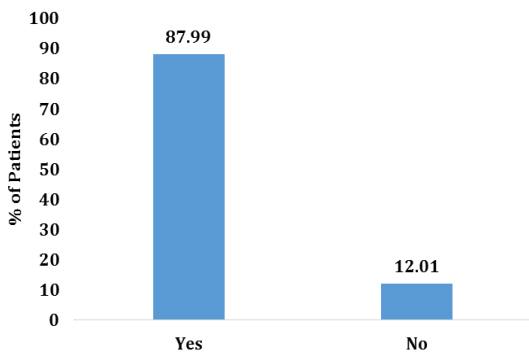


Figure-4: Adherence to medications among the study group

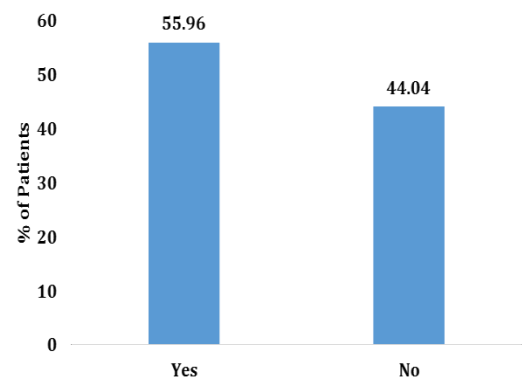


Figure-3: Adherence to hemodialysis sessions among the study group

More than two third of patients (77%) had a hospitalization history. The mean level of pre-hemodialysis serum potassium (K⁺) was 5.10374 ± 0.906054 mmol/L; range between (2.700 to 10.200 mmol/L). The mean level of pre-hemodialysis serum phosphorus (po₄) was 5.32851 ± 1.756836 mg/dl; range between (1.300 to 11.600 mg/dl).

Prevalence of Adherence Behavior:

The table shows that, the prevalence rate of adherence were high among all four categories (dietary, fluid, medications and attendance to dialysis sessions) being the highest adherence rate was for diet (88.37%) and the lowest was for attendance to dialysis sessions (55.96%); the majority of patients were adhere to diet, fluid and medications (88.37%, 87.78% and 87.99%, respectively) and nearly half of patients were adherent to dialysis sessions (55.96%).



Figure 1 shows that the majority of patients (87.78%) were adherent to their fluid restrictions recommendations and only (12.22%) of them were non-adherent to those recommendations. Figure 2 displays that most of patients (88.37%) were adherent to their diet restrictions recommendations and only (11.63%) of them were non-adherent to those recommendations. From figure 3, it can be seen that about half of patients (55.96%) were adherent to attending to their hemodialysis sessions compared to (44.04%) of them were non-adherent to attending to their sessions. Figure 4 demonstrate that the majority of patients (87.99%) were adherent to their medications recommendations and only (12.01%) were non-adherent to those recommendations.

Discussion

To determine the frequency and prevalence of nonadherence in patients with ESRD undergoing HD, a clearcut and consistent definition of these terms is essentially needed. Owing to the inconsistencies in uniform definitions, widely divergent results have been obtained in different studies, so that as many as 80% of HD patients may be considered noncompliant with oral medication.[24,29] The data of the previous studies revealed that the calculated median is closer to 50%.[22]

Standardized adherence parameters that can be easily measured and verified would be desirable to achieve reproducible and accurate rates of non-adherence. Non-adherence to treatment by HD patients is quite common, but it is difficult to quantitatively measure this condition, and there is no agreement regarding how exactly to define noncompliance.

The prospective observational Dialysis Outcomes and Practice Patterns Study (DOPPS) used skipping of more than 1 dialysis session, shortening a dialysis session by >10 minutes, serum potassium concentration of >6.0mEq/L, phosphate level of >2.4 mmol/L or IDWG >5.7% of body weight as measures of non-adherence.[30] In our study, we also measured skipped and shortened HD sessions, serum phosphorus and potassium level and IDWG.

Hemodialysis places multiple and unavoidable demands on a patient's lifestyle, related to the dialysis regimen, dietary and fluid restrictions, the requirement for multiple medications with potential side effects, as well as management of multiple co-morbid conditions. Adherence with various aspects of management is uncommon and is understandable from the patient's perspective.[17] Our study was conducted to describe adherence behaviours of patients on maintenance HD in a comprehensive way by identifying the prevalence of adherence behaviours, and determining non-adherence risk factors in patients on maintenance HD.

Based on the demographic findings of our study, the majority of the study sample had poor socioeconomic status, as reflected in high levels of unemployment (66.20%), low monthly incomes (72.85% had less than 3000 RS), and low educational levels. Ward (2008)[31] examined the incidence in 747,556 adults with ESRD in the U.S. population from January 1, 1996, to June 30, 2004, and reported that incidence of ESRD was different according to socioeconomic status. The incidence of ESRD caused by all primary kidney diseases was greatest in those in the lowest socioeconomic score and decreased with higher socioeconomic status. Thus, the current sample adequately reflects the general Saudi population from the socioeconomic standpoint where individuals with lower socioeconomic status were at greater risk for ESRD.



Adherence rates to HD (missing and shortening HD), medication, and fluid and diet restrictions in the current study population were 55.96%, 87.99%, 87.78%, and 88.37%, respectively. Previous studies reported adherence rates to attendance at HD, medications, and fluid and diet restrictions from 100% to 67.7%, 98.8% to 19%, 96.6% to 26%, and 98.8% to 17.6%, respectively.[30,32-35]

Since the previously reported adherence rates have been extremely varied, it is difficult to compare measured adherence rates in this study to those reported by others. When compared to the reported adherence rates using self-report instruments, the study conducted by Kugler and colleagues (2005)[36] reported non-adherence rates as high as 74.6% and 81.4% to fluid and diet restrictions from 916 patients in Germany and Belgium, respectively. They used the Dialysis Diet and Fluid Non-Adherence Questionnaire (DDFQ), the only available self-report instrument with proven validity and reliability. Overall adherence rates in this study population are thought to be higher than our study. Perhaps this is related to the different study settings, measurement instruments, and/or the recruitment procedures employed for the study. Another study conducted by Chan, et al 2012[37] in Malaysia and found the adherence rates of dietary, fluid, medication and dialysis were 27.7%, 24.5%, 66.5% and 91.0%, respectively.

Prevalence of adherence behaviour of patients varied between studies according to the cut-point used to establish compliance criteria, where more stringent cut-points inflated the percentage and more lenient cut-points reduced the percentage. Thus, there is a need to establish uniform criteria in order to test real differences in compliance between patient groups vs. simply differences in measurement). The reported adherence rate for our sample is high, but the rates of adherence to HD (missing and shortening HD), were relatively low. It is speculated that this findings are related to the increased degree of difficulty following treatment recommendations for HD sessions guidelines; perhaps following HD sessions recommendations require more appropriate knowledge and skill and more willpower of patients. Among limitations of the current study, some of patients might have not enough time to complete the questionnaire; therefore, the tools were as concise as possible. Language barriers as some patients do not speak Arabic, therefore the questionnaires were bilingual. The main limitation of this study is its cross-sectional design for the first two objectives. A longitudinal design might be better suited to explore indications of causal relationships and would help to display changes of over time.

Conclusion:

In conclusion, the study showed that the prevalence of adherence among our HD patients was within the range of most published international studies.

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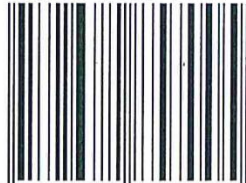
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