An assessment of residential exposure to environmental noise at a shipping port

Abstract. The World Health Organisation has recently acknowledged that contrary to the trend for other environmental stressors, noise exposure is increasing in Europe. However, little research has been conducted on environmental noise exposure to handling activity at shipping ports. This paper reports on research examining the extent of noise exposure for residents within the vicinity of Dublin Port, Ireland using the nation's largest port terminal as a proxy for port noise. In order to assess the level of exposure in the area, long-term measurements were undertaken at the most exposed residential façade for a period of 45 days to determine the extent of night-time exposure was above levels recommended by the World Health Organisation. The indicators L_{90}, L_{eq} and L_{Max} were used to determine exposure levels. The results show that exposure is above night-time guideline limits set down by the WHO and is above Irish levels for triggering a mitigation response and highlight the extent to which port noise can be a significant environmental stressor. The research also investigated the extent of low-frequency noise (which is associated with greater health issues) from night-time port handling activity and found a significant low-frequency component indicating the negative health issues that might arise from port noise exposure more generally. We also undertook semi-structured interviews with residents to qualitatively assess the self-reported impact of prolonged night-time noise exposure for local residents.

Introduction

Since the establishment of the European Noise Directive in 2002, there has been a significant improvement in awareness among the general public and policymakers about the relationship between human exposure to environmental noise and related public health concerns (Murphy and King, 2010). As a result, the importance of environmental noise pollution in shaping urban, environmental and public health policies throughout the EU and internationally is increasing albeit at a relatively slow pace. The recent publication by the World Health Organisation (2011) of its seminal *Burden of Disease from Environmental Noise* document sets out not only the evidence-base on the health effects of environmental noise in Europe but also attempts to quantify the extent of the problem. The report estimates that DALYs[1] lost due to environmental noise are '…60000 years for ischaemic heart disease, 45000 years for cognitive impairment of children, 903000 years for sleep disturbance, 21000 years for tinnitus and 587000 years for annoyance' (WHO, 2011, 101). The evidence emerging from the document informed the recently established WHO European health policy – Health 2020[2].

[1] Disability-adjusted life years
[2] http://www.euro.who.int/en/what-we-do/event/first-meeting-of-the-european-health-policy-forum/health-2020

Moreover, the document elucidates the extent to which noise pollution is a serious public health problem pointing out that noise pollution ranked second among a series of environmental stressors for their public health impact in a selection of European countries. Indeed, contrary to the trend for other environmental stressors (e.g. second hand smoke, dioxins and benzene), which are declining, noise exposure is actually increasing in Europe (WHO, 2011, 1).

Since the introduction of the Directive and with it the initiation of the strategic noise mapping process (see Murphy and King, 2010), there has been significant and large-scale research undertaken in the EU investigating the extent of population exposure to noise. Notable examples in the EU include Murphy et al (2009); Garai and Fattori (2009); Licitra (2011); Murphy and King (2011) and Vogiatzis (2012), but similar research has also been initiated in other jurisdictions (see Ausejo, 2010; Wang and Kang, 2011; Lam and Ma, 2012). As a result of the completion of the first phase of noise mapping, the EU estimates that 40.2 million citizens suffer from excessive exposure to night-time road traffic noise alone; when aircraft, rail and industrial sources are also considered the figure rises to 48.8 million (Guarinoni et al, 2012).

The health issues associated with excessive exposure to environmental noise pollution (particularly from transportation sources) are now fairly well-established and extensively documented (see King and Davis, 2003; Muzet, 2007; Murphy et al, 2009; Pirra et al, 2010) . The primary impacts are annoyance and sleep disturbance (Murphy and King, 2011), with night-time noise the major source of concern. Urban traffic noise is the main noise source followed by neighbourhood noise and then aircraft noise (Muzet, 2007). The reported effects on sleep disturbance tend to be a reduction in the sleep period, arousals, awakenings, sleep stage modifications and autonomic responses (e.g. change in heart rate) (Vallet et al, 1983; Carter, 1996; Babisch et al, 2005). Moreover, the reduction in sleep quality has secondary impacts (generally felt the day after disturbance) including fatigue, low work capacity, reduced cognitive performance, changes in daytime behaviour as well as mood changes and associated negative emotions. In fact, recent research findings by Rabat et al (2005) suggest that chronic exposure to environmental noise can lead to a permanent disruption in sleep.

The relationship between low frequency environmental noise exposure and health related problems have been less of a focus in the academic literature than noise in the traditional A-weighted bands. Although exact definitions are difficult to pinpoint, low frequency noise is generally taken to be noise from 10Hz to 200Hz with noise below 20Hz being referred to as infrasound (Leventhall, 2004). Most walls in buildings tend to be deficient in attenuating noise in the low frequency region (Leventhall, 2003) meaning that residential exposure to low frequency noise is an even greater problem than in the normal frequency range; obviously this is a considerable problem from the viewpoint of environmental noise exposure and public health issues.

Moreover, the available evidence suggests that low frequency noise may have even more detrimental impacts on public health than noise in A-weighted frequency bands. The WHO recognise the special place of low frequency noise as an environmental problem suggesting that 'low-frequency components in noise may increase the adverse effects considerably' (Berglund et al, 1999, 61). Persson and Bjorkman (1988) and Persson et al (1990) found that dB(A) underestimates the level of annoyance for low frequency noise. This, along with other related work implies that noise at low frequencies is considered more annoying by individuals (Broner, 1978; Berglund et al, 1996; Pawlaczyk-Luszczynska, 2010). Moreover, related research has also found that low frequency noise has a greater degree of 'unpleasantness' than noise in the A-weighted frequency bands (Inukai et al, 2000; Nakamura and Inukai, 1998). Exposure to low frequency noise also causes sleep disturbance (Leventhall, 2003) and its associated secondary effects with the WHO (Berglund et al, 1999) noting that it 'can disturb rest and sleep even at low sound levels'. Indeed, Ising and Ising (2002) have shown that noise, perceived as a threat, stimulates the release of cortisol in the body which may interrupt recreative and other sleep qualities. Their work has demonstrated that low-frequency noise seriously impacts on the sleep quality of children. Moreover, Persson-Waye et al (2002) have shown that adult exposure to low frequency traffic noise is associated with greater degrees of fatigue and a negative mood.

Other research on low frequency noise and health has indicated that it has an impact on peripheral task performance (Kyriakides and Lebenthall, 1977) while more recent research has shown it negatively affects demanding verbal tasks in the work environment (Persson-Waye et al, 2001). Ising and Ising (2002) demonstrated that compared to a control group, children exposed to low frequency noise have significantly more problems with concentration and memory. In public surveys conducted to assess subjective well-being for individuals exposed to low frequency noise, Moller and Lydoff (2002) found multiple self-reported health effects including disturbance when falling asleep, awakenings, frequent awareness of the noise, irritation, and disturbance when reading. Other effects reported were insomnia, lack of concentration, headaches, and palpitations. A laboratory study by Persson-Waye et al (1997) showed that subjects exposed to low frequency noise were less happy and had a poorer social orientation. Moreover, Persson-Waye and Bengtsson's (2002) work suggests that low frequency noise represents 44% of all noise complaints in Sweden.

Very little research has been undertaken in the academic literature analysing the extent of environmental noise at shipping ports even though industrial noise is a strategic noise category in the existing Environmental Noise Directive (END) of the EU (EU, 2000; Murphy and King, 2010). Even less has been conducted analysing residential exposure to low frequency noise as a result of port-related activity. One exception in this regard is the EU-funded NoMEPorts project which aims to reduce noise, noise-related annoyance and health problems of people living around industrial port areas. That project recently produced a 'Good Practice Guide on Port Area Noise Mapping and

Management' document which outlines a common approach for port area noise mapping and management within the context of the Environmental Noise Directive (van Breeman, 2008).

Bearing the foregoing context in mind, the current study investigates residential noise exposure at a shipping port in Dublin, Ireland, with particular emphasis on low frequency noise content. The research had two core objectives. The first was to investigate the extent of night-time noise in the study area during periods of night-time port activity and non-activity[3]. Thus, we assessed whether an environmental noise problem exists in the area during night-time. The second was to specifically assess the presence of a low-frequency noise problem in the area during night-time port activity versus non-activity. In this regard, the research investigated the merit of using the dB(C-A) indicator as a means of detecting low frequency environmental noise in conjunction with 1/3 octave analysis for assessing noise at narrower frequencies. We also used interviews with residents of the area to qualitatively gauge self-reported subjective views of the dose-effect relationship in the study area.

Methods

Context

Dublin port is Ireland's largest port by volume of tonnage handled and number of vessels received on an annual basis (Dublin Port Company, 2012). The port is a state-owned commercial company charged with operating and developing Dublin Port. In an Irish context Dublin Port is unique in that all cargo handling activities are provided by private sector companies who compete against each other. Activity at the port has increased dramatically over the last twenty years and the recent Dublin Port Master Plan, 2012-2040 envisages conservative estimates of throughput growth of 2.5% per annum until 2040 handling up to 60 million tonnes of goods at that point (Dublin Port Company, 2012).

In Dublin, Marine Terminals Ltd (MTL) operate a terminal for the Dublin Port Authority at Pigeon House Road in Dublin Docklands. It is a Lo/Lo (lift on/lift off) container terminal and is Ireland's 'largest and most modern container terminal' (McDonald, 2011) with three (45 tonne) ship to shore gantry cranes which can handle up to and including Panamax size vessels. Secondary handling of cargo is carried out by four (40 tonne) rail mounted gantries (RMG's) which are aided by various ground-handling equipment and there are also 300 reefer points[4]. The berth is 700 metres long (see Figure 1). The facility is located directly across from an area where 11 residents have their

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[3] We define port-activity as activity associated with the loading/unloading of a container ship including industrial and associated ground transport noise.

[4] A reefer point is the power supply that a refrigerated container plugs in to.

homes, many of them for a substantial number of years. Thus, they are highly susceptible to noise being emitted from the facility (see Figures 1-2).

Three gantries were erected without planning permission in 2002 but no enforcement proceedings were brought against the company prior to the seven-year period for enforcement under planning laws expiring (McDonald, 2011). Thus, much of the activities in terms of operational hours and excessive noise levels remain unregulated. There has already been some evidence that the residents are suffering extensively from exposure to environmental noise including sleep deprivation and the associated secondary health stressors of that exposure (McDonald, 2011). The main noise sources at the location include:

- Movement of cranes along the crane rails
- Reversing sirens of the cranes
- Noise from stationary vessels (engine noise)
- Banging of unloaded shipping containers
- Ground vehicle movement to support unloading and stacking of containers (e.g. shunting vehicles)
- Other unidentified noise (perhaps LFN)

Measurement and statistical analysis

In order to assess residential exposure to noise in the study area a series of long term measurements were carried out at the port terminal. Figure 1 shows a map of the study location, the port area operated by MTL, the Coastguard resident's area as well as the location of the sound level meter (SLM) erected for long term measurement. The calibrated SLM was erected at a secure location 1.5 metres from the residential façade and at 4 metres above ground level (see Figure 2). This was in accordance with ISO-1996-1(2003). The location of the SLM was directly across the road from the activity site (c. <10 metres). Continuous measurements, logged in 15 minute measurement periods were taken for a period of 45 days between April 22nd and June 6th, 2012.

We logged noise information using the L_{90} (as a background noise indicator) and L_{eq} indicators for the entire period. However, our analysis was concerned primarily with the night-time period which was taken to be from 23:00-07:00 hours in line with the END's recommendation. In addition, we used the WHO guideline limit of 40 dB(A) during night-time for assessing potential health implications of the results (WHO, 2009). We were also interested in assessing the intermittent nature of the noise activity given the different noise sources alluded to already so information was logged for L_{Max} during the measurement period. Laboratory studies using recorded intermittent and continuous traffic noise have demonstrated beyond any reasonable doubt that human subjects are more disturbed by intermittent noise than by continuous noise (Ohrstrom and Rylander, 1982) and L_{eq} does not seem to be a good predictor of sleep disturbance. Indeed, as far back as the 1970s, Vernet (1979) found a low correlation between L_{eq} and the number of sleep disturbances for people exposed to road and rail traffic noise; by way of comparison, the same study found a strong correlation between the number of disturbances and sleep stage changes with the maximum noise level and number of noise events. L_{Max}, which highlights the maximum noise level reached during the measurement, is therefore useful as an indicator of the disturbance caused by intermittent noise. Each of the foregoing indicators were logged for both A and C-weighted noise. We had co-operation from the residents association in logging night-time handling activity at the site which enabled us to gain a more complete picture of the data being logged and allowed for cross-checking of noise levels with related night-noise activity at the site.

For the statistical analysis, independent-samples T-tests were conducted in order to assess whether there was a statistically significant difference in the mean noise level during nights of port activity versus non-activity for the various noise indicators being used. In line with that suggested in the literature (Sterne and Davey-Smith, 2001), we used a conservative alpha level of 1% as the threshold for assessing statistical significance. We also tested the data for homoscedasticity (using Levene's test) and adopted the appropriate p-value depending on whether equal variances could be assumed or otherwise.

Detecting Low Frequency Noise

In the literature, a number of methods have been used for the detection of low frequency noise problems (see Leventhall, 2003). One of those focuses on the difference between C and A-weighted noise levels due to the difference being an indicator of the amount of low frequency energy in the noise as well as a useful predictor of annoyance (Holmburg el al, 1997; Kjellberg et al, 1997). Kellberg et al's work (1997) suggests that if the difference between the noise values for the two weightings - dB(C)-dB(A) - is greater than 15 dB, there is potential for a low frequency noise problem. Similar guidance exists in Australia where the New South Wales Industrial Noise Policy (INP) recommends that a 5 dB modifying factor be added to the outdoor A-weighted sound pressure level when the 'C' weighted sound pressure level minus the 'A' weighted sound pressure level difference is 15 dB or greater (Broner, 2011).While this indicator does not provide definitive proof of a low frequency noise problem, it points to the need for further investigation within narrower frequency bands. The research of Kjellberg et al also suggests that if the 15dB value is exceeded, a useful rule of thumb is to add 6 dB to the corresponding A-weighted value to determine the equivalent level of annoyance and nuisance. In our work, we used the dB(C)-dB(A) indicator and the 15dB threshold as means of detecting the potential for low frequency noise in the study area prior to spectrum analysis being conducted.

Spectrum Analysis

To account for the tonal aspect of some noise sources ISO 1996-2 and BS 4142 (1997) include a rating level which accounts for the tonal and impulsive elements in the noise spectrum. This involves adding an adjustment to the measured L_{Aeq} level in order to better describe public response to the more annoying noise source. In general, the presence of a tone can be determined by comparing the level in one 1/3rd octave band to the level in the two adjacent bands. The level difference may vary with frequency. ISO 1996-2 suggests the following:

- 15 dB in the low-frequency one-third-octave bands (25 Hz to 125 Hz),
- 8 dB in middle-frequency bands (160 Hz to 400 Hz),
- 5 dB in high-frequency bands (500 Hz to 10 000 Hz).

Furthermore the spectrum analysis can be used to assess the prevalence of low frequency noise in the source.

Table 1. Criteria for the control of annoyance due to low frequency noise

Broner and Knight-Merz (2011) propose simple criteria (Table 1) for the control of annoyance due to low frequency noise. If the noise level is fluctuating by 5dB(C) then a penalty of 5dB(C) should be added i.e. the criteria should be reduced. A further procedure for the assessment of low frequency noise is presented by Newman and McEwan (1980) who reference a British Gas Corporation criterion for specifying noise control for gas turbines. This involves a 60 dB limit in the 31.5 Hz octave band at the nearest dwelling. In order to examine the potential presence of tonal elements and further investigate low frequency noise in the study area, further measurements were acquired in 1/3 octave bands during activity at the port (July 2nd).

Dose-Effect relationships

In order to assess dose-effect relationships we undertook interviews with two out of the 11 residences the vicinity of the port (see Figure 2). Undertaking questionnaire surveys would not have proved fruitful given the small number of residents in the area. Thus, we undertook semi-structured interviews as a means of getting more in-depth qualitative information relating to the self-reported and subjective effects of noise on residents in the study area. We asked questions verbally in a manner consistent with the general-purpose noise reaction questions suggested by Fields et al (2001) as well as probing other potential impacts of exposure. Although these guidelines were developed primarily for questionnaire surveys, the principles contained therein were a useful base for conducting semi-structured interviews on dose-effect relationships for the current study. Thus, a semi-structured interview guide was drawn up to address themes focussing on the nature and description of the night-time sound, dose-effect issues including frequency and duration of sleep disturbance and awakenings as a result of port noise and its secondary effects, the extent of annoyance including associated emotions and the overall quality of life impacts including other behaviour effects of exposure of night-time noise at the port. The interviews lasted between 30-40 minutes each.

Results

Night-time environmental noise

Tables 2 displays the measurement results using the various A and C-weighted indicators measured during the night-time period. From a public health perspective, night-time noise-related annoyance and sleep disturbance are considerably more detrimental to public health than day-time exposure so the analysis was focussed on these results. For the A-weighted results, it can be seen that when the measured $L_{90,8hrs}$ values are considered for nights with no activity (38.0) versus those with activity (42.3), an average difference of 4.3dB is evident. This indicates that activity at the site has a considerable impact on raising background noise levels in the study area.

Turning to the $L_{eq,8hrs}$ values, it is evident the mean value during nights with activity was c. 3.3dB higher (46.0) when compared with nights of no activity at the site (42.7). However, what is important to note here is that when we analyse the $L_{eq,8hrs}$ data against the true background noise level (i.e. $L_{90,8hrs}$ with no activity – 38.0), it can be seen that noise during activity nights is 8.0 dB above true background levels. This indicates that activity significantly alters the quality of the sound environment in the area and in a negative manner. Indeed, the impact that activity has on the noise environment is further highlighted by Figure 3. It displays data for the average $L_{eq,15\ mins}$ with and without activity highlighting the extent to which night-time noise during nights with port handling activity is considerably above the corresponding value without activity.

L_{Max} is a good indicator of the degree of intermittency of noise in the study area and of the noise peaks in the vicinity which may disturb sleep negatively (see Pearsons et al, 1995; Vallet, 2003). This is particularly useful in the current context given the nature of the noise in the area which includes numerous short bursts of loud noise from the loading/unloading of containers, reversing sirens etc. If the mean $L_{Max,8hrs}$ values are considered (Table 2), it can be seen that they are considerably higher during nights of activity (59.7) than nights of no activity (55.5); a difference of 4.2dB. The graphical depictions of the results for $L_{Max,\ 15mins}$ during activity versus no activity highlight the degree to which the soundscape is altered (Figure 4). In relative terms, the results show that the extent to which activity is affecting the L_{Max} indicator is greater than for the other indicators analysed implying that activity nights are characterised by intermittent noise peaks which may have a significant impact on sleep disturbance in the study area.

In order to test the hypothesis that site activity significantly affects the noise environment negatively in the study area more comprehensively, an independent samples t-test was conducted. The results are displayed in Table 3. It can be seen that there is a statistically significant difference (p=0.000) for all indicators between noise levels during nights of activity versus nights of no activity. This demonstrates that the higher levels of noise during nights of activity is not due to chance but is due to the noise being produced as a result of port handling activity. Moreover, it is interesting that the results are significantly different irrespective of the noise indicator being used – L_{90}, L_{eq}, L_{Max} – highlighting the extent to which noise from port activity fundamentally affects the night-soundscape in the study area negatively.

The foregoing results are particularly important from public health perspective. They imply that during nights where activity is present, the noise level exceeds the WHO night-noise guideline limit of 40 dB(A) by more than 6.0 dB(A), L_{eq}. This implies that there is a potentially significant public health problem in the area. Even if the Irish EPA onset guideline values for triggering a noise mitigation response (which were used under the first phase of the END) are considered - 45 dB(A), L_{night} - the problem is considerable enough to warrant a mitigation response.

Low-frequency noise

As mentioned already, Kjellberg et al. (1997) have suggested that if the difference between A and C-weighted values exceeds 15dB then a low frequency noise problem may exist. Our results show that during nights where activity exists the dB(C)-dB(A) value is 13.6 dB; the corresponding value for nights with no activity is 12.6 dB. While the difference between dB(C)-dB(A) is greater during nights of activity, it does not exceed the 15dB threshold suggested by Kjellberg et al (1997). The difference is depicted graphically in Figure 5 for $L_{eq,15mins}$ values and highlights the inconclusive nature of the difference between the dB(C)-dB(A) values with and without activity. This indicates that there may not be a significant low frequency problem in the study area. Despite this, the graphical depiction of $L_{eq,15\ mins}$ for C-weighted noise (Figure 6) shows that noise levels are consistently higher throughout the night-time period during nights when there is port handling activity. Indeed, the gap between C-weighted noise levels during activity versus no activity is considerably greater than those for A-weighted noise (Figure 3) indicating the presence of low-frequency noise during nights of handling activity. In order to investigate this issue more comprehensively, a spectrum analysis was conducted in the area using 1/3 octave analysis for assessing the extent of noise in the lower frequency bands during site activity.

Spectrum analysis

Six fifteen minute 1/3 octave noise measurements were taken during night-time port activity. The overall A and C-weighted values are reported in Table 4 while Figure 7 plots the average spectrum of noise during activity. No tones were identified using the methodology outlined in ISO 1996-2. The port noise appears as a broadband source and has clear low frequency content.

The measured noise levels are in breach of the proposed criteria set out by Broner and Knight-Merz (2011). Furthermore, by logarithmically adding the 25Hz, 31.5 Hz and 40Hz third octave band levels it is possible to compare the measurements with the 31.5Hz octave band criterion of 60dB set by the British Gas Corporation. This level is exceeded by approximately 3.4 dB indicating that low frequency noise is likely to be adding to the overall night-time sleep disturbance and annoyance level in the area. Given that the results here show that low frequency noise is significant in the area, an additional weighting factor of 5 dB can be added to the average A-weighted value during night-time. This suggests then that noise exposure in the area is 11.0 dB above recommended noise limits set by the WHO. Overall, the results show that noise levels during night-time are exacerbated even further from a health perspective by the presence of a significant low frequency component.

Dose-effect relationships

The results from the interviews undertaken with residents are highly revealing in that they elucidate the qualitative impacts of sleep disturbance and annoyance on local residents. The noise being experienced during the night-time is intermittent noise and the following quotes describe the nature of the sound being experienced:

> *'…there's the noise of the cranes moving, the engine and the crane moving again. It's very definite metal-on-metal; very definite. You could hear practically every single container as it moved…you can certainly hear bangs and they're loud enough to jolt you. It's not a pleasant noise. Underneath you have the constant hum of an engine; it's kind of a dull type sound as well, but then you've got a sharp bang. You sometimes get a very high-pitched sound from the metal on metal.'* (Interview 1)

In health terms, the largest impact on residents is the sleep disturbance associated with night-time noise as outlined by the following quotes:

> *'To be honest it doesn't keep me awake all night; but it keeps me awake when I initially go to bed and eventually I'll fall asleep. But then typically I might wake up during the night. I might wake up and [younger child] would wake up.'* (Interview 1)

'I would say on average 2 to maybe 3 times during the week you would be affected. The worst is when they start working at 11 and work through the night. The thing is that they might just have to move one or two containers and if they do that badly at any time in the middle of the night they wake you up; so that's your sleep pattern gone.' (Interview 2)

Indeed, both of the interviewees highlighted that the noise also affected the sleep quality of their children:

'[Young child 1], who is twenty months; he is woken up by the bangs, and that wakes my partner up and that wakes me up. [Young child 2] used to be woken up more; now it tends to be that she starts to…shout out a bit. So it's definitely, if it's not waking her up its bringing her sleep to a different level of sleep – so taking her out of a deep sleep into something else; certainly a fright…' (Interview 2)

The interviewees also highlighted the secondary effects of noise that are largely felt the day after a night of sleep disturbance (Murphy et al, 2009). These effects include fatigue, irritability, reduced productivity and are highlighted in the following quotations:

'I think I have a constant tiredness that I didn't have before; an underlying tiredness. It takes me longer [in the morning] to kind of kick into action. But what I find difficult then during the day is…it affects how you behave; it affects your mood very definitely. I find I'm snappier, I'm more irritable, and I wouldn't have been like that before. I find I'm not very patient, whereas before I used to be quite patient. I am normally somebody that would have good energy levels; I'm not a very lethargic person. I think it does definitely affect your character. I'm not normally a moody person.' (Interview 1)

'It makes me agitated when it's happening outside, and therefore makes me more kind of stressed. You know sometimes you go to bed at half ten, eleven and you sleep for four hours and then you get a bang; and because you've had four hours sleep you're actually rested to an extent but you're not very well rested, so you can get up at 8 o'clock the next morning and you don't feel that bad, but by lunchtime you're irritable, you know, you're focus is gone.' (Interview 2)

The foregoing results provide additional qualitative insights which supplements and is consistent with the aforementioned measurements results and statistical analysis in relation to the extent of night-time noise in the vicinity of the port. They highlight the self-reported and subjective human cost associated with excessive night-time noise in the area.

Conclusion

Three key conclusions can be drawn from the study results. First, the study has provided analysis of environmental noise exposure at a shipping port which of which there are very few similar studies in the academic literature. Our study shows that environmental noise at shipping ports have the potential to be significant public health concerns unless they are tightly regulated and appropriate noise management and mitigation measures are implemented to prevent long-term exposure. In the specific case of Dublin, the results reveal a significant environmental and public health concern for residents in the immediate vicinity of the port. As a result of night-time handling activity, WHO guideline night-time noise limits (40 dB(A)) are consistently exceeded in the area with the noise being intermittent in nature and thus providing for potentially greater shocks to residents' sleep patterns. This demonstrates convincingly, that night-time handling activity at the port has a detrimental and significant impact on the soundscape of the area. Moreover, the night-time activity appears to be characterised by little or no attempt to mitigate the noise. In this sense, our results suggest that mitigation measures either through restriction/cessation of operational activity during night-time hours or some other measure should be instituted as a priority not only in this area but more generally wherever port handling activity is operating adjacent to residential neighbourhoods. Implementation of the port noise management strategy described in van Breeman (2008) would be useful in this regard.

Second, the results also demonstrate the presence of a significant low frequency noise component during port handling activity. Given that the research alluded to already has suggested low frequency noise is a greater health risk than noise at other frequencies, this is rather worrying from a public health perspective. It implies more generally that shipping port handling activity is associated with noise that has a significant low frequency component. Our results show that whether noise exposure is assessed in the traditional A-weighted frequency band or at lower frequencies, night-time noise exposure in our study area is excessive relative to limits in other countries. The fact that noise in the area is characterised by a significant low frequency component suggests the potential health implications of exposure are even greater than would be expected under normal conditions where low frequency noise is not present. If A-weighted $L_{eq,8hrs}$ noise levels are adjusted for the low frequency component, the results show that noise in the area exceeds WHO limits by approximately 11dB.

Third, an insightful component of the results was the self-reported impacts of noise exposure through qualitative interview. Although they do not provide conclusive evidence of the health impacts of excessive exposure, they demonstrate the human consequences of sleep disturbance and annoyance associated with over-exposure. In this sense the qualitative data emerging from interview tallied closely with scientific data emerging about the effect of exposure in humans (WHO, 2011). The impact of exposure in terms of sleep disturbance and the secondary impacts in terms of fatigue, reduced productivity, anger, lack of motivation and focus were all expressed through the interview data. Thus, we feel that including qualitative data from interviews in future studies is a very useful way of supplementing the scientific data emerging through measurement and statistical analysis.

Finally, it is perhaps worth noting that $L_{eq,8hrs}$ is not, in our view, an appropriate indicator for the assessment of sleep disturbance. In our study, it was clear that night-time noise associated with this indicator significantly underestimated the extent of sleep disturbance and annoyance. Indeed, the problem with the accuracy and representativeness of current night-time noise indicators has been highlighted as a priority are for further research in a recent EU study (Guarinoni et al, 2012). Given that noise from port activity in our study was highly intermittent, the actual impact of exposure in terms of sleep disturbance and annoyance was highly conservative when averaged over an 8 hour period. Future research should prioritise the appropriateness of $L_{eq,8hrs}$ as an indicator of sleep disturbance and annoyance and it should be modified to better reflect the negative impacts of night-time exposure. In cases where it continues to be used, non-acoustic indicators (e.g. noise complaints, interviews etc) should be used in conjunction with $L_{eq,8hrs}$ to gauge the level of disturbance more accurately.

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Figure 1. Study area, SLM and Coastguard Residents' location

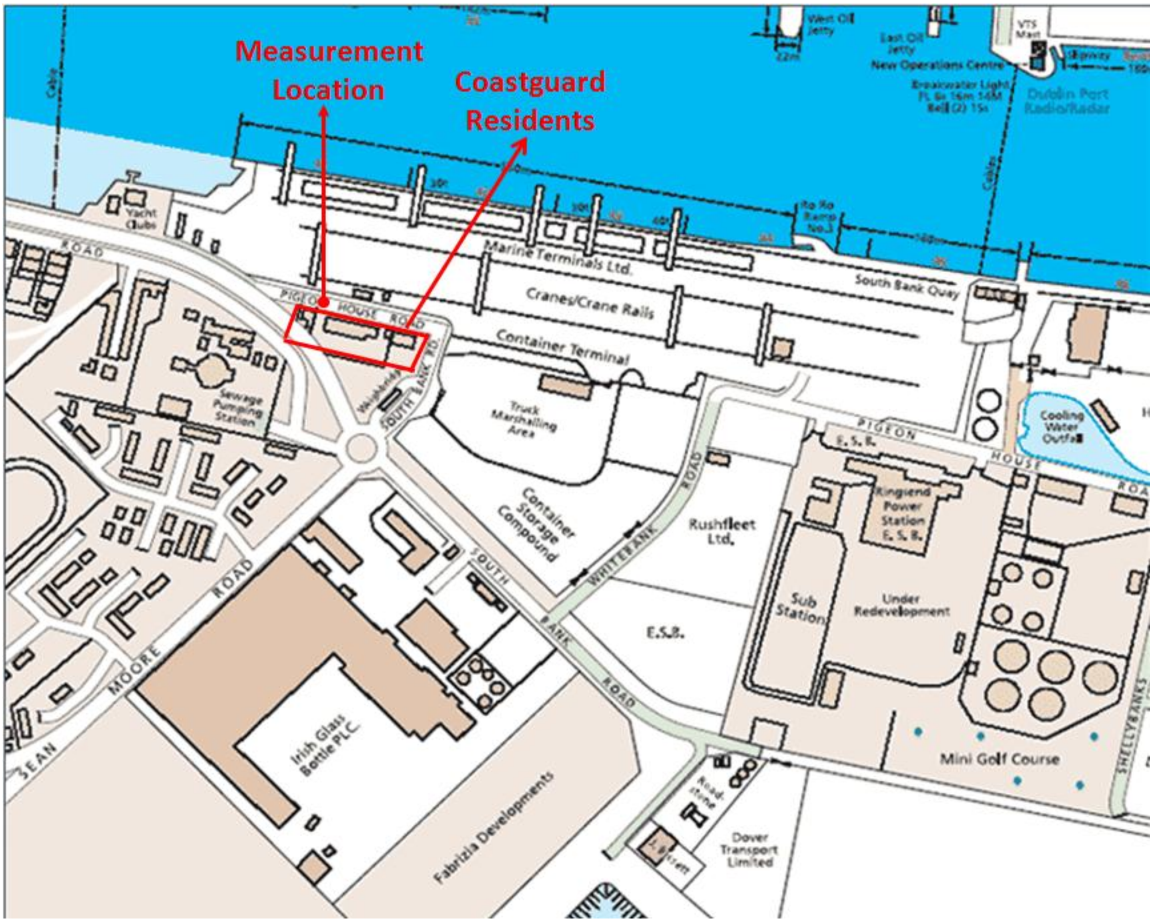

Figure 2. Gantry cranes at MTL Ltd. Terminal, Pigeon House Road, Dublin Port (view from equipment position

Figure 3. $L_{eq,\ 15mins}$ Results for A-weighted Results for Night-time Noise

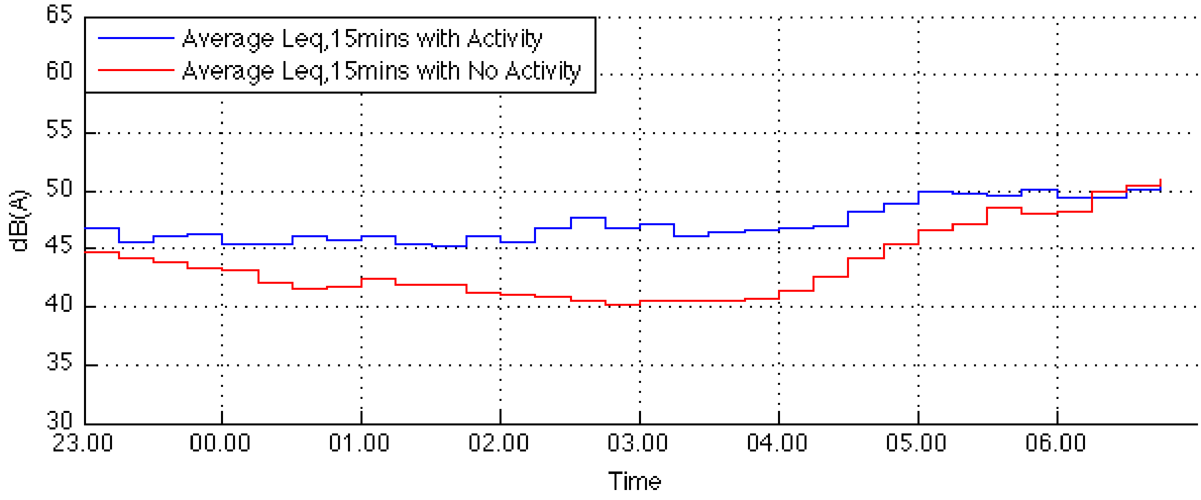

Figure 4. $L_{Max,\ 15mins}$ Results for A-weighted Results for Night-time Noise

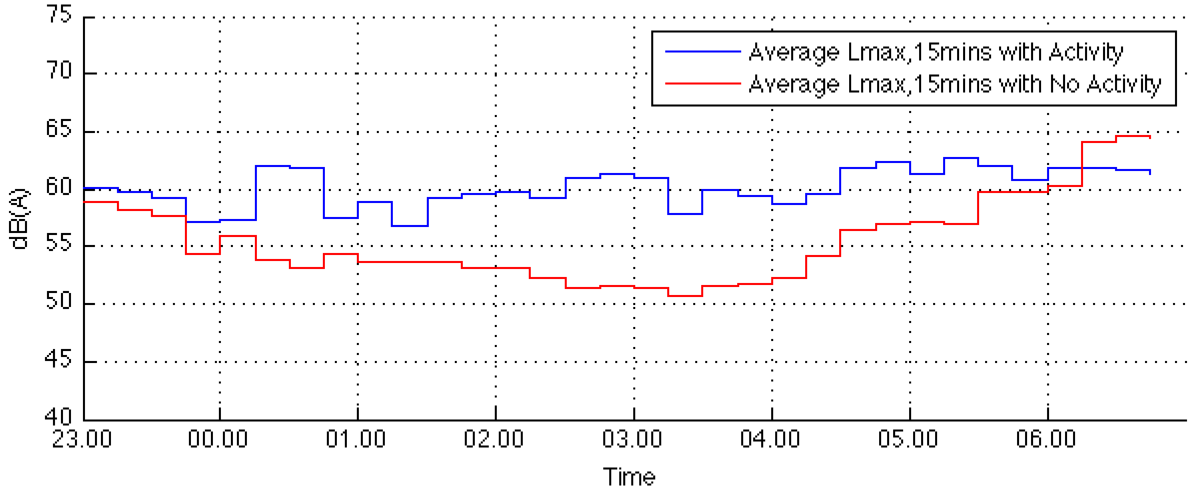

Figure 5. $L_{eq,\ 15mins}$ Results for A and C-weighted Night-time Noise

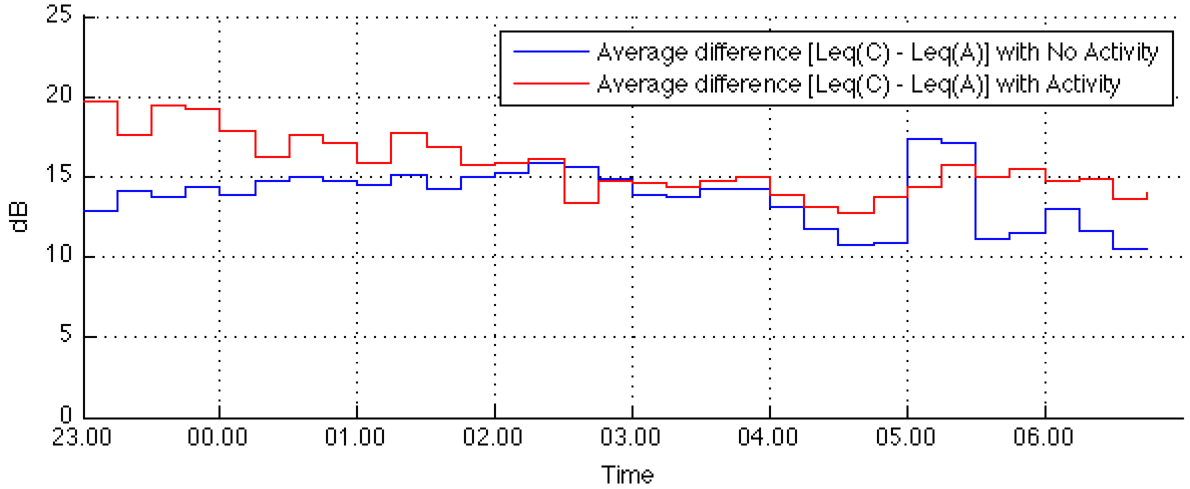

Figure 6. $L_{eq, 15mins}$ Results for C-weighted Night-time Noise

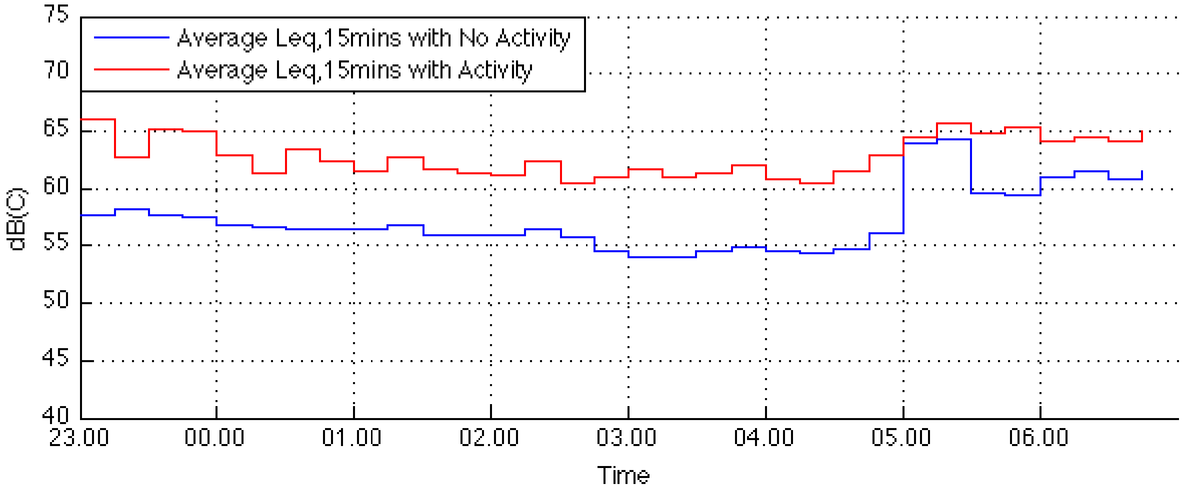

Figure 7. Spectrum analysis at the port

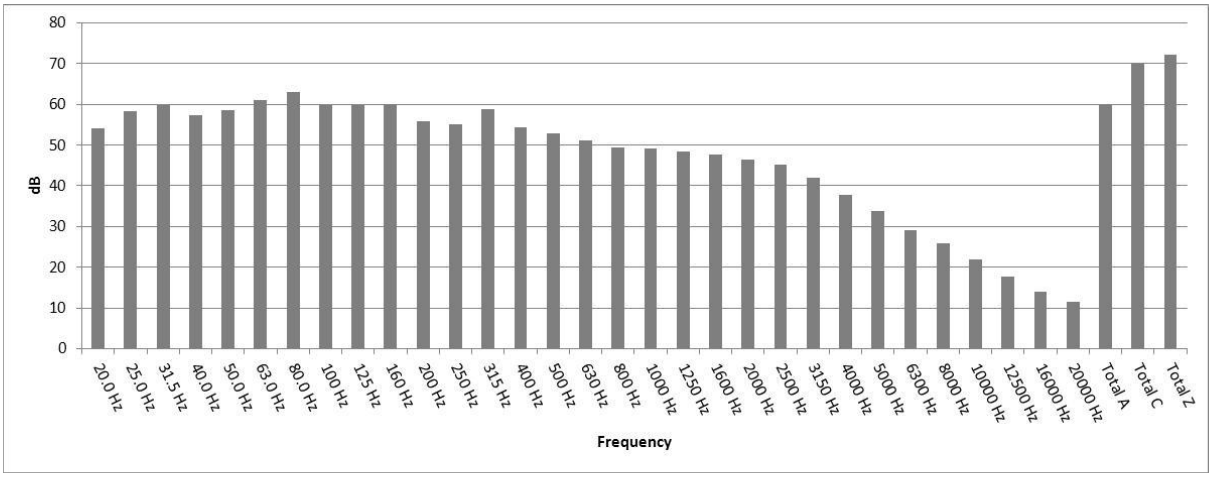

Table 1. Criteria for the control of annoyance due to low frequency noise

Sensitive Receiver		Range	Criteria L_{eq} (dB(C))
Residential	Night time or Plant operation 24/7	Desirable	60
		Maximum	65
	Daytime or Intermittent (1-2 hours)	Desirable	65
		Maximum	70

Table 2. Descriptive statistics for each noise indicator

	Activity	N	Mean	Std. Deviation	Std. Error Mean
LMax(A)	No Activity	1081	55.4	6.4	0.1
	Activity	288	59.7	5.8	0.3
Leq(A)	No Activity	1081	42.7	4.2	0.1
	Activity	288	46.0	3.7	0.2
L90(A)	No Activity	1081	38.0	3.8	0.1
	Activity	288	42.3	3.5	0.2
LMax(C)	No Activity	1081	68.2	6.5	0.2
	Activity	288	74.9	9.0	0.5
Leq(C)	No Activity	1081	55.2	4.7	0.1
	Activity	288	59.6	5.4	0.3
L90(C)	No Activity	1081	51.1	3.9	0.1
	Activity	288	54.1	3.3	0.1

Table 3. Independent Samples T-test for each noise indicators – activity versus no activity

	t-test for Equality of Means						
						95% Confidence Interval of the Difference	
	t	df (degrees of freedom)	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
LMax(A)	-10.750	491.384	.000	-4.24268	.39468	-5.01814	-3.46722
Leq(A)	-12.078	1367	.000	-3.31135	.27417	-3.84919	-2.77351
L90(A)	-16.983	1367	.000	-4.30137	.25328	-4.79822	-3.80451
LMax(C)	-11.773	371.694	.000	-6.70919	.56988	-7.82979	-5.58860
Leq(C)	-12.307	413.513	.000	-4.32592	.35149	-5.01685	-3.63499
L90(C)	-13.142	519.665	.000	-3.04746	.23188	-3.50301	-2.59192

Table 4. 1/3 octave night-time measurements during port activity

Sample Beginning 03:03 July 2nd	**L_{eq}(A)**	**L_{eq}(c)**
Sample 1	61.7	72.1
Sample 2	61.7	72.1
Sample 3	60.6	70.6
Sample 4	59.3	69.2
Sample 5	58.9	68.4
Sample 6	58.7	67.1