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# Workstation design in industrial halls with many noise sources using acoustic modeling and substitute sources

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**Summary**
This paper presents the authors' approach for acoustic modelling of component production hall were lots of hand-held tools and machinery are used. The goal is both to create an acoustic map and to determine average daily noise levels at workstations. In order to optimize calculations, substitute sources for each production station were created and the interrelations between the geometry of source-worker system and the average noise levels for workers of the station were defined. The detailed approach would require the simulation for each specific setup of sources and employees. The proposed approach allows to reduce the number of sources in the model and allows to consider only one setup. This paper compares the results of detailed simulations and simulations using the presented methodology. Paper presents the potential of this method and possible applications.

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## 1. Introduction

Noise prediction in workrooms using software acoustic models gives very good results for stationary well defined noise sources. It is affordable even for complex models. More sophisticated situation, where there are lot of movable sources, like hand-held tools and machinery, poses a lot of trouble and need individual approach. The methodology presented below describes the authors' approach developed for such situation in order to optimize calculations. Simulated noise levels for the proposed method were compared with the detailed one and difference in results was established.

## 2. Description of the situation

The venue of the project is a large component production hall where there are hundreds of workers. They are divided into groups of 5-20 people to make the operations on an object in separated stations. Workers of each group do noisy operations around their own object such as welding, cutting, hammering. A detailed production task list of production cycle for each station is known.

### 2.1. Overview

Workers of the station do operations for their immediate needs. Operations are made with hand-held machinery and tools and they are localized on the object. The overall period for operations with each tool is known from the production task list. The object with defined dimensions is a component of production. The Figure 1. presents a possible setup of sources and workers on the station for a random moment of production cycle.

### 2.2. Expectations

We are expected to predict:

a) the average noise exposure level of workers for each station,

b) the acoustic map for the hall,

c) effectiveness of possible noise reduction solutions for workstations and hall,

when the production setup changes.
In order to meet the expectations of the client the creation of the parametric model of production hall is necessary.


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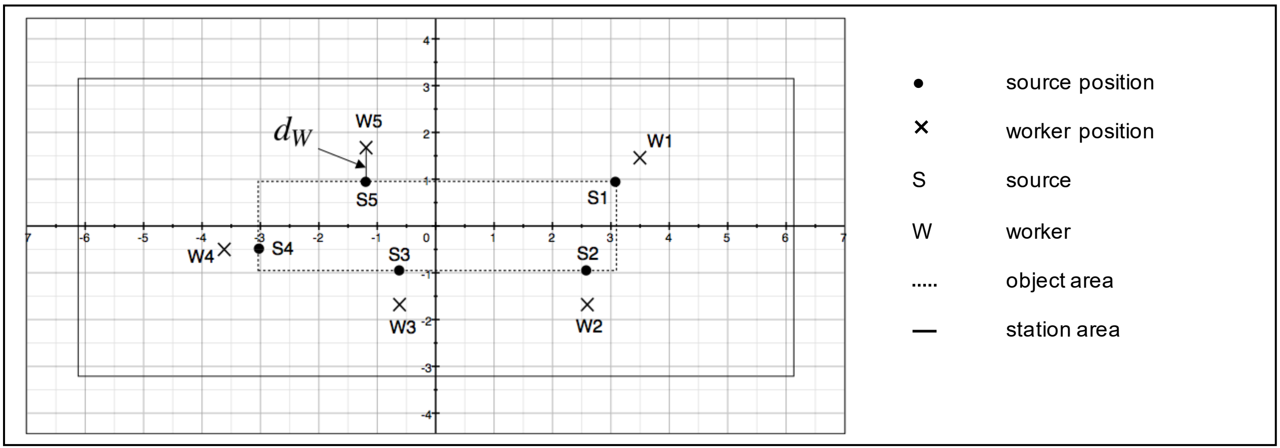


Figure 1. Possible setup of sources (S) and workers (W) on the station for a random moment of production cycle, where dots mark the position of sources and crosses mark the position of workers. Grid in metres.

### 2.3. Input parameters

The input data for the parametric model are as follows:

a) production task list containing each operations period,

b) used tools and its operations mode,

c) number of workers on the stations,

d) dimensions of the object,

e) average distance between an worker and his source during the operation,

f) localization of the stations and fittings in the hall.

## 3. Prediction method

In order to optimize calculations and simplify situation some assumptions ware made and substitute model of the station was created. The goal is to have possibility to meet all expectations of project with known value of uncertainty.

### 3.1. Assumptions

A. The source of noise for the operation is located in contact point between a tool and an object during the operation. The transmission sound from that point over the object is irrelevant and all radiation if present, rises the emission only from that point. Sources are described by their sound power level established by measurement during the operation.

B. During the production cycle sources on the station can be localized anywhere on the object edges. For calculation of noise levels for the production cycle we cannot use fixed position of sources because workers move with tools around the given object to make necessary operations.

C. During the operation a worker is in assumed average distance from his source. Out of all these averages the average distance $d_W$ for all workers of the station was calculated. It is assumed that we could determine the noise emission from a source to operator’s position according to ISO 11203 knowing only the sound power level and the distance from the source.

D. Workers from a group on a given station are in near field from all sources in that station.

E. Stations’ center points are at least twice of the maximum object dimension away from one another.

### 3.2. Substitute model

Taking into account assumptions from section 3.1. a substitute source for each station was decided to use. It is suitable for a calculation of noise emission from stations (noise mapping), but not for meeting the expectations of noise exposure calculation for workers. To achieve that, it was decided to define a substitute distance from that source, where the value of sound level will be equal to average noise exposure level of workers. The intention was to keep the opportunity to test the influence of interior parameters and noise transmitted from other stations in predicted value of noise exposure.

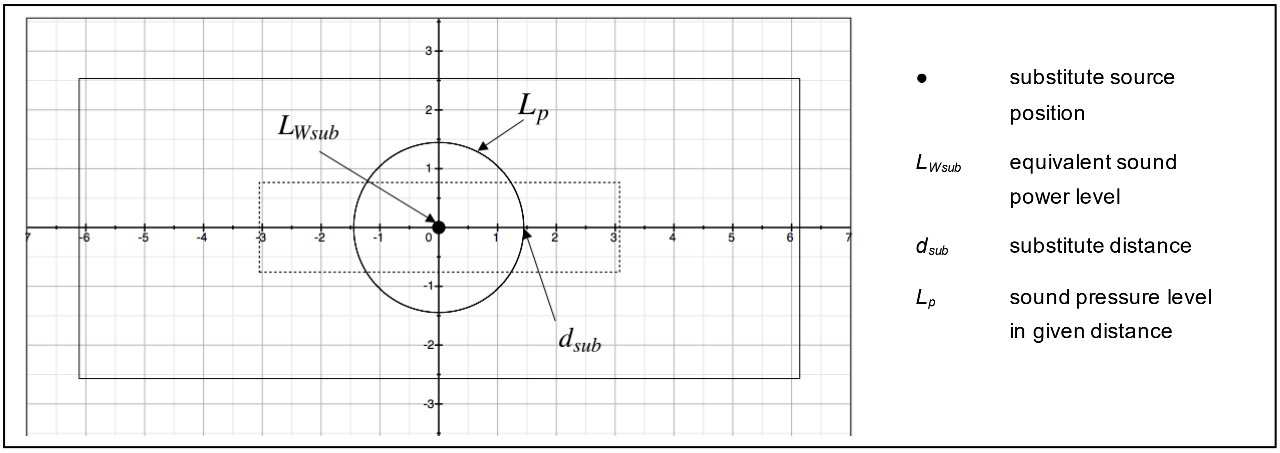


Figure 2. Proposed substitute model of the station with substitute source and substitute distance.

### 3.2.1. Substitute source

The substitute source is localized in geometrical center of the object. Sound power level of the source $L_{Wsub}$ is equivalent for all operations on the station and it will be calculated as a total of all operation power levels referred to its periods during production cycle (Figure 2.). Input parameters *a* and *b* from section 2.3. are applied.

### 3.2.2. Substitute distance definition

Due to assumption *B* from section 3.1. it was decided that evenly distributed sources over the circle can substitute every possible setup of sources during production cycle (Figure 3). The radius *R* of a circle was defined as an average distance from geometrical center of an object to each point of its edge.

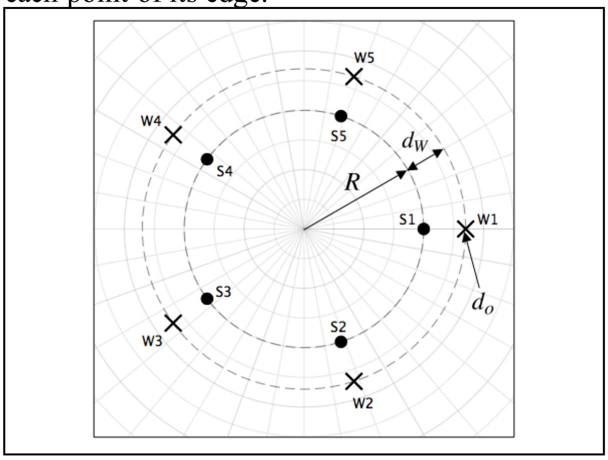


Figure 3. Detailed model of the station, where ● – (S)ources, × – (W)orkers, R – radius of sources setup, $d_o$ – radius of workers setup, $d_W$ – source-worker distance.

Each operator is exposed to noise from each source (Figure 4) depending on the distance

$$d_k = \sqrt{R^2 + {d_o}^2 - 2Rd_o\cos\left(2\pi\frac{k-1}{W}\right)}, \quad (1)$$

where $d_o = d_W + R$, $k = \{1,2,\ldots,W\}$.

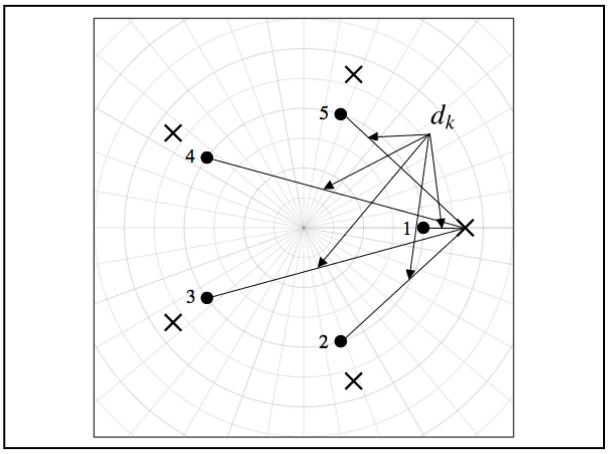


Figure 4. Distance $d_k$ from worker to each source in system.

An average sound pressure level of an operator's positions could be calculated.
If the substitute source is used, that level could be calculated around that source in substitute distance (see Figure 2) which is defined as follows:

$$d_{sub} = \sqrt{\frac{W}{\sum_{k=1}^{W} 10^{-\log\left({d_k}^2\right)}}}. \quad (2)$$

Substitute distance is parametrized by number of workers *W*, radius of sources setup *R* and average source-worker distance $d_W$ (input *c*, *d*, *e* from section 2.3.) and it was tested.
Value of $d_{sub}$ is limited by:

$$\lim_{R\to 0} d_{sub} = d_W,$$
$$\lim_{R\to\infty} d_{sub} = d_W\sqrt{W}. \quad (3)$$

For given number of workers *W=5*, substitute distance varies depending on the distance $d_W$ as shown in Figure 5.
For given distance $d_W$*=0.7m*, substitute distance varies depending on the number of workers as shown in Figure 6.

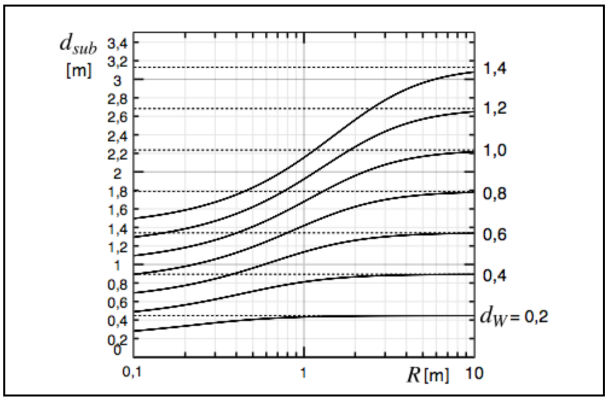


Figure 5. Substitute distance varies depending on avarage distance beetwen operator's position and his source for constant number of workers $W=5$. Doted line shows upper limit value of $d_{sub}$, see equation (3).

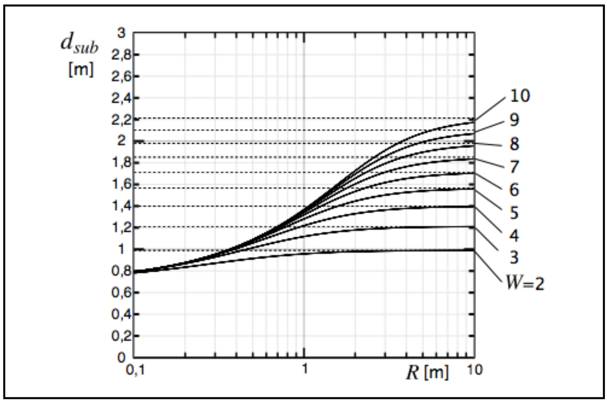


Figure 6. Substitute distance varies depending on the number of workers for constant source-worker distance $d_W=0.7m$. Doted line shows upper limit value of $d_{sub}$, see equation (3).

## 4. Test of substitute model

Software Odeon 11 Industrial was used for all tests. Box–shaped empty room with dimensions $L_X=20m$, $L_Y=30m$, $L_Z=5m$ was used. Environment was prepared in four variants of adaptation: free field, reflecting plane, reflecting floor and walls, reflecting room. No scattering coefficient values were define, only 100% absorbent and 100% reflecting materials were used.
Simulations were done for assumed model of a station as shown on Figure 3 and for substitute model as shown on Figure 2 depending on input parameters change ($W$, $R$, $d_W$). Example of used models are shown on Figure 7. Models were located in the center of a room. Each worker do the same bench of operations. Results of average sound level on operator's position were compared. Difference between this value calculated using substitute model and assumed model of the station were presented in Figure 8.

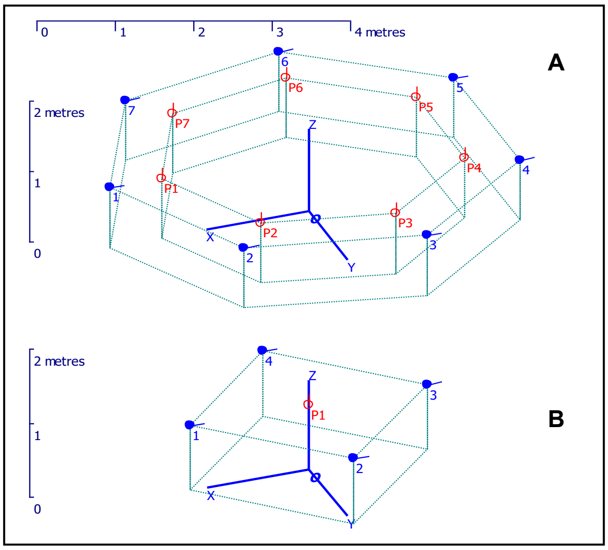


Figure 7. A) Model of the station for simulation based on assumptions from section 3.1. for $W=7$; $R=2m$; $d_W=0.7m$ and B) its substitute model. Calculated substitute distance equals $1,6m$.

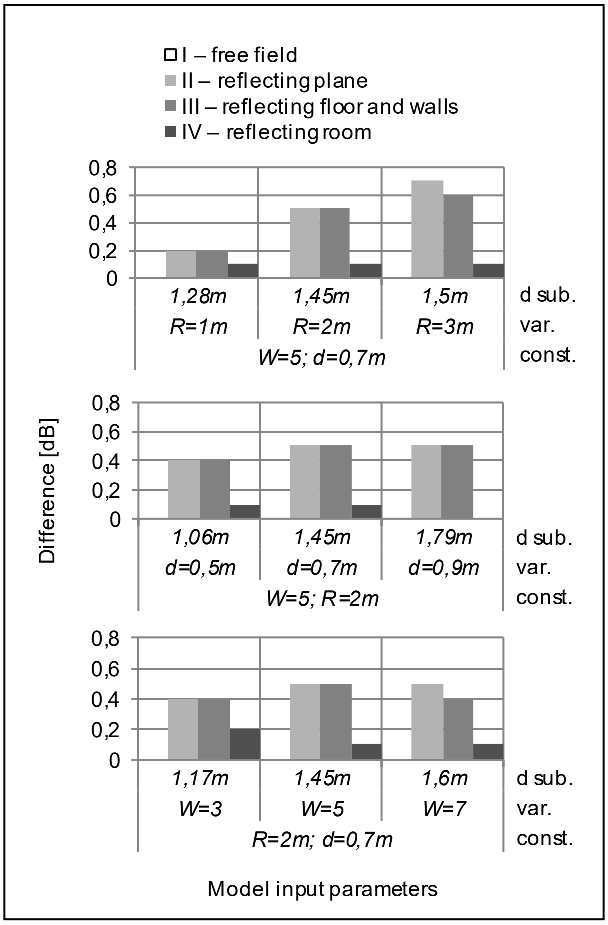


Figure 8. Difference between average sound level at operator's position calculated using substitute model and assumed model of the station: variable $R$, variable $d$, variable $W$. I-IV – variants of adaptation, $W$ – number of workers, $R$ – radius of the object, $d=d_W$ – source-worker distance.

## 5. Implementation

This section presents step-by-step implementation for comparable situations.

### 5.1. Collection of input data

1. Measurements for several different operation modes to determine average sound power level for the operations with each type of tool. Measurements according to ISO 3744 and ISO 3747 with reference sound source to determine the environmental correction.
2. Average distance from a worker to his tool during the operation.
3. Reverberation time according to ISO 3382-2.
4. Dimensions of the object.
5. Interior surfaces material and fittings.
6. Production task lists for each station.

### 5.2. Environment modelling

Level of detail of that model as high as it is needed to achieve the measured value of environmental correction K2 on the stations and reverberation time in the hall.

### 5.3. Workstations modeling

Substitute model for each station depending on collected data.

## 6. Conclusion

Using substitute model causes nearly the same value of average noise levels at operator's positions compering with detailed approach (Figure 8). In environment where strong reflection from one surface is present substitute model gives higher value proportional to dimension of the source-worker setup $R$, because of assumption D from section 3.1. is not fulfilled. It could be avoided if sources in model will be placed on the floor without elevation, but it is needed to achieve required transmission of noise out of station.

All assumptions must be carefully investigated before using this method. In further research comparisons with measurements are needed. But there is very hard to carry out measurements of workers exposure in described situation. They are expensive because of time needed to obtain required uncertainty. Calculation method seems to be more useful because of possibility to indicate environment influence and possibility to calculate effectiveness of noise reduction solution. Computer model are accurate but calculations tools long and the time is proportional to number of used sources. For very large halls with lots of sources such simplification are needed, especially if we want to give clients wide range of possible solutions with calculated effectiveness. Substitute model could help designing low-noise workstations taking into account number of workers, source-worker setup and production task list in the concerned area.

## References

[1] ISO-3740 series.

[2] ISO 11200 series.

[3] ISO 11690-3.

[4] ISO 14257.