Cost reduction of noise treatments in the oil & gas industry - design of noise mitigation for gas compressor stations using engineering optimisation

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ABSTRACT

The capital cost of noise control treatments for land-based gas compressor stations can be significant. Field gas compression facilities can have many noise sources including compressors, fan coolers, power generators or transformers, pipes and valves, flares and so on. Some coal seam gas field facilities can also have co-located water treatment plant or water transfer pumps. Environmental noise computer modelling predictions can estimate the component contribution noise emissions from each individual noise source at each affected receiver. Using these data, an experienced practitioner can estimate a scheme of noise level reductions for each source so that the noise emissions of the entire site comply with the overall environmental noise targets at the receptors. However it is not straightforward to select and design the noise control treatments for all of the individual noise sources with the explicit goal of minimising the total capital cost for the overall noise mitigation program. This paper provides an example of minimising the cost of noise control treatments required for a coal seam methane gas field compression station using two different engineering optimisation techniques.

Keywords: Noise Control, Cost, Optimisation I-INCE Classification of Subjects Number(s): 52.5; 55

1. INTRODUCTION

The cost of noise control treatments can be a significant capital outlay for coal seam gas (CSG) projects. CSG projects are known for having many wells distributed over wide areas of land, as well as several compression stations more sparsely located throughout the gas field.

If there are receptors within audible distance of a compression station, it may be necessary to install noise control treatments to some plant items in order to achieve the noise limits. Environmental noise modelling software can tell you the required noise level reduction for the entire compression facility, but it is up to the acoustic designer to decide the noise level reduction that should be applied to each individual noise source. Since all engineering design tasks must consider cost as one of the design parameters, the acoustic designer is obliged to incorporate the cost of the noise control treatments that they select into their considerations. If the designer intends to achieve the required noise control outcomes for the best value for money, it will be necessary to incorporate the costs into the calculations in a robust and defendable manner, for which a mathematical process will be required. If minimising the cost of noise control treatments for the plant is considered to be the highest priority, then the selection and design of the treatments can be undertaken using an engineering optimisation technique.

2. OPTIMISATION

A definition of mathematical optimisation is the process of attempting to find the best element from some set of available alternatives subject to a set of constraints.

Many numerical techniques exist to seek the optimum result without evaluating all possible alternatives (Ravindran et al 2006). In practice, real optimisation problems are computationally too difficult to uncompromisingly seek only the absolute best possible outcome and instead must aim to achieve the best achievable result with the available computing power and time.

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In mathematical notation the optimisation problem is stated simply as:

$$\max_{x \in X} f(x) \quad \text{to maximise some variable}$$

or

$$\min_{x \in X} f(x) \quad \text{to minimise a cost function, eg. a cost function}$$

$$f : R^n \rightarrow R$$

$$x \in R^n$$

Subject to:

$$h_i(x) = 0, i \in I = 1, \ldots, p$$

$$g_j(x) \leq 0, j \in J = 1, \ldots, m$$

The theory and practice of optimisation exists with the deliberate purpose of achieving better overall outcomes than the much more common approach of satisficing, which seems to be prevalent among many engineering fields. Satisficing is the process by which the designer and customer only aim to achieve satisfactory results because the satisfactory position is familiar, hassle-free, and secure, whereas aiming for the best-achievable result would call for costs, effort, and incurring of risk. (Simon H 1982).

However, in relatively large engineering projects the extra effort and associated labour costs involved in refining the design would usually reap large financial rewards because the capital cost savings typically far outweigh the extra design fees. This is particularly true if the design refinements are undertaken with the specific purpose of reducing costs and maximising the engineering design's overall value for money.

In this paper, two methods of optimisation are used and compared:

1. an Evolutionary Algorithm (EA), which is a variant of the Genetic Algorithm (GA) technique, and
2. the proprietary optimisation algorithm called 'Expert System Industry' implemented by the environmental noise modelling software package SoundPLAN (version 7.3).

The practical application of these two methods is illustrated through a case study using simulated receptors, noise sources and noise treatments similar to real situations encountered in Australia in recent years.

2.1 Evolutionary Algorithm

The Evolutionary Algorithm is an advanced version of the Genetic Algorithm optimisation method. Genetic algorithms are based on the principles of natural selection according to Darwin's theory of survival of the fittest. Genetic or evolutionary algorithms can sometimes be useful for combinatorial optimisation problems in which the variables can only take discrete values because of the extremely large number of potential combinations of different variables. Genetic/evolutionary algorithms are usually very successful at finding good local minima/maxima, although there is no way of knowing if the procedure has found the global optimal solution. A basic software implementation of the evolutionary algorithm is provided with Microsoft Excel (2010) and a more powerful version is available from Frontline Systems Inc. Implementations of genetic and evolutionary algorithms are also available in numerical computing software including MATLAB and Scilab.

2.2 SoundPLAN's Expert System Industry module

The proprietary environmental noise modelling software SoundPLAN features a numerical optimisation algorithm which can select noise control mitigation treatments from a predefined library with the express purpose of minimising the cost of the entire noise control scheme for all sources. The software documentation does not describe the mathematical algorithm that the software module follows, however by inspection and experimentation its fundamental method can be deduced. After analysing and experimenting with several test models it appears that the algorithm incrementally applies noise control treatments in a forwards-only direction of progressive advancement. It seems that it discretely adds or replaces noise control treatments with the sole selection criteria of achieving the best incremental increase in the total noise reduction for the smallest increase in total cost. Furthermore, it seems that the algorithm is not recursive, which means that it does not consider the viable option of downgrading noise mitigation at one source in order to allow an improvement in the overall noise reduction per dollar by improving the noise mitigation at another source.

3. NOISE SOURCES AND RECEPTORS

The CSG gasfields in Australia are characterised by large areas of land with many hundreds of gas wells and large compression stations interspersed between small rural communities and isolated residences. The distances between receptors can range between a few tens of metres to several kilometres in any direction. The distances between the gas compression facilities vary, but may be tens of kilometres. In the case study described in this paper, a simulated total of 29 receptors were located within an area of 10km x 10km. In Australia, gas compression and water treatment facilities are almost always placed in areas where the nearest receptors are at least several hundred metres or several kilometres away, as shown in Figure 1.

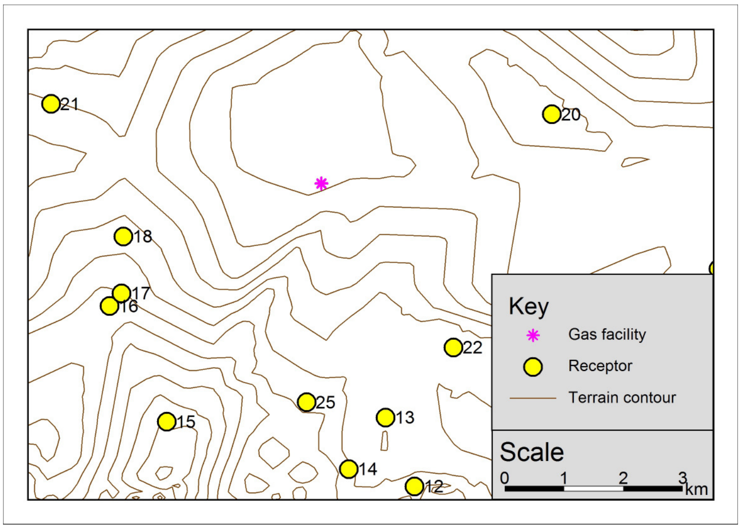

Figure 1 – Locations of gas compression facility and noise receptors

3.1 Noise sources sound emissions

The noise sources used in the case study were the screw compressors and ancillary plant such as electric motors and coolers, and the associated gas turbine power generators.

The sound power levels of the plant items were similar to those that are currently being designed at the writing of this paper for installation in some CSG fields in Australia. The corresponding noise mitigation treatments were also based approximately on the noise control treatments currently being designed for these gas compression facilities in Australia. The costs are fictitious and indicative only.

The sound power level spectra of the unattenuated compression facility's noise sources are shown in Table 1. The attenuations of the available source noise control treatments are shown in Table 2.

Table 1 – Sound power levels of unattenuated gas compression plant noise sources (SWL, dB re 10^{-12}W)

No. of	Plant Item	Octave Band (Hz)								Sum dB(A)
		63	125	250	500	1k	2k	4k	8k	
7	1st stage LP Screw Compressor	72	87	95	99	106	123	111	100	124
7	2nd Stage HP Screw Compressor	73	88	96	100	107	124	112	101	125
7	Electric Motor (x2)	70	82	89	95	98	99	96	87	104
7	Fan Cooler (x2)	87	96	100	101	101	95	91	83	106
5	Generator – casing	75	86	94	101	100	101	97	88	106

No. of	Plant Item	Octave Band (Hz)								Sum dB(A)
		63	125	250	500	1k	2k	4k	8k	
5	Generator - Air Inlet	83	97	104	97	87	74	103	93	108
5	Generator - Exhaust	94	97	102	106	98	94	91	84	109
5	Generator - Lube Oil Cooler	85	92	93	93	94	91	87	79	100
5	Generator - Cooler Fan (x4)	85	94	98	99	99	93	89	81	104

Table 2 – Available noise mitigation treatments, dB

Treatment	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	Cost
Enclosure 1	0	8	8	11	21	24	16	12	$10,000
Enclosure 2	0	10	19	21	26	34	17	13	$13,000
Enclosure 3	5	10	21	39	46	41	18	14	$16,900
Enclosure 4	5	11	27	42	46	41	19	14	$21,970
Cooler Treatment 1	0	1	3	8	6	3	0	0	$20,000
Cooler Treatment 2	2	8	10	16	14	10	0	0	$28,000
Cooler Treatment 3	9	13	15	18	20	11	0	0	$39,200
Cooler Treatment 4	15	18	22	28	30	25	10	7.5	$54,880
Muffler 1	0	0	0	2	5	2	0	0	$5,000
Muffler 2	0	2	3	5	8	2	0	0	$9,000
Muffler 3	0	3	4.5	7.5	12	3	0	0	$16,200
Muffler 4	0	4.5	6.75	11.25	18	4.5	0	0	$29,160

The noise mitigation treatments shown in Table 2 are mutually exclusive and cannot be combined additively. Therefore only one of the four options for each type of plant can be used for each plant item. Including the null treatment option, there are five options available for each source.

The number of potential combinations of noise control treatments for the noise sources shown in Table 1 and the treatments shown in Table 2 (as well as the null (untreated) option for each source) can be estimated. If the number of treatment options was limited by decreeing that all noise sources of the same type must have the same noise treatment, then with 9 types of noise sources and 5 options for each source, the number of treatment schemes is 9^5= 59,049. If all noise sources were allowed to have noise control independently assigned, then the number of potential noise treatments schemes is 82^5=3,707,398,432 which is obviously too many to calculate manually.

3.2 Noise receptors and criteria

The noise receptors simulated in the case study described in this paper were isolated residences separated by various distances ranging from a few hundred metres to several kilometres apart, representing mostly farmhouses. The ambient noise levels in this type of area are typically quite low (often less than 25 dB(A)). In different regions in Australia, the legislated noise level limits at isolated residences in quiet areas are either based on the existing background noise level (eg. background + 3 dB(A) which can be different for each receptor) or all receptors can be given a common threshold noise limit eg. 28 dB(A) or 30 dB(A).

The predicted noise levels at the receptors from the untreated noise sources are shown in Table 3. The predictions were undertaken according to ISO9613.2.

Table 3 – Predicted noise levels at receptors from unattenuated plant, Leq dB(A)

Rec. No.	Leq dB(A)	Rec. No.	Leq dB(A)	Rec. No.	Leq dB(A)	Rec. No.	Leq dB(A)	Rec. No.	Leq dB(A)
1	14	7	16.8	13	28.9	19	21.8	25	30.3
2	13.1	8	14.1	14	26.6	20	29	26	19.2
3	15	9	19.2	15	27	21	27.2	27	20.9
4	14	10	21.3	16	28.9	22	30.8	28	22.8
5	16	11	21.9	17	32.3	23	19.1	29	13.8
6	16.6	12	25.2	18	33	24	19.8		

4. METHODOLOGY

The calculation methodologies for the two optimisation methods are necessarily quite different. The EA method can be written in a suitable programming language, or employed in numerical computation software such as MATLAB, Scilab or a spreadsheet package that includes the algorithm such as Microsoft Excel. The method to use the Expert System Industry optimisation module in SoundPLAN is described in the software documentation.

4.1 Evolutionary Algorithm usage

The process of using an optimisation technique such as an EA to design a noise control treatment program is to take the normal procedure of predicting the noise levels at receptors, break it into its component steps and allowing the algorithm to control the input to one of the prediction's calculation steps. In this case the pertinent step in the propagation calculation is the attenuation of the noise source due to the application of noise control treatments. In the ISO9613.2 procedure, this occurs in the A_{misc} step. This is shown schematically in Figure 2.

The set of variables that the algorithm can manipulate is simply the choice of which noise control treatment is to be applied for each of the sources. The decisive constraint with which the algorithm must comply is that the resultant noise levels at all receptors must comply with the noise limit assigned to each individual receptor.

The genetic/evolutionary algorithm works by splitting and joining previously successful noise mitigation schemes (the 'parents'), and keeping only those new combinations (the 'children') whose overall result (in this case the total cost) is better (ie. cheaper) than the 'parents'.

The optimisation problem using the EA was undertaken for two design scenarios, as follows:

1. Design noise level 28 dB(A)
2. Design noise level 30 dB(A).

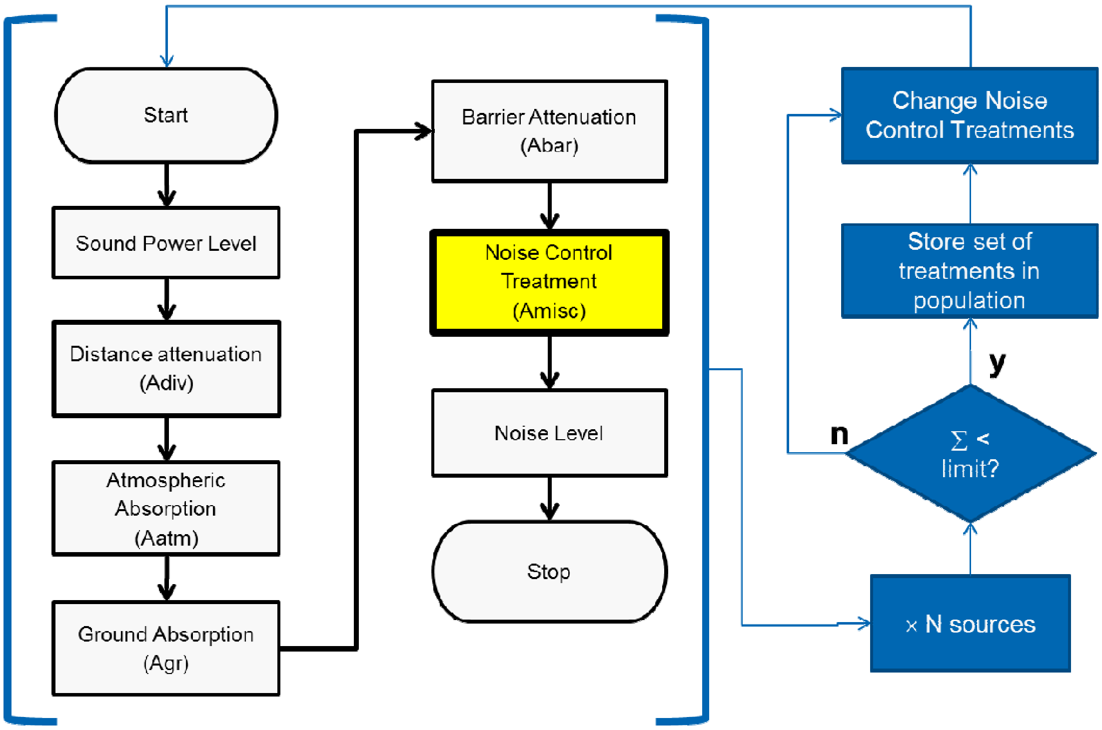

Figure 2 – Initial set-up of Evolutionary Algorithm starting population for design of noise control

4.2 SoundPLAN – Expert System Industry usage

The optimisation problem using SoundPLAN's software module was undertaken for the same two design scenarios, as follows:

1. Design noise level 28 dB(A)
2. Design noise level 30 dB(A).

5. RESULTS

5.1 Evolutionary Algorithm Results

5.1.1 Design noise limit: 28 dB(A)

The calculation was run many times to seek the global optimum, however the results did not converge to a solution that may have been the lowest possible minimum cost. The total costs for the four best results were:

- $1,387,600
- $1,368,400
- $1,366,600
- $1,366,400

The selected noise control treatments for the lowest cost result of $1,366,400 are shown in Table 6.

Table 6 – Noise mitigation scheme for 28 dB(A) limit, EA method, all noise sources independent

Compressor Train Noise source	Compressor Train Number						
	1	2	3	4	5	6	7
1st stage LP Screw Compressor	E1	E1	E1	E1	E1	E1	E1
2nd Stage HP Screw Compressor	E2	E1	E1	E1	E1	E1	E1
Electric Motor - LP Screw Comp	-	-	E1	E1	E1	E1	-
Electric Motor - HP Screw Comp	E1	-	-	E2	E2	-	E1
Fan Cooler	C2	C2	C2	C2	C2	C2	C2
Fan Cooler	C2	C3	C3	C3	C3	C3	C3

Power Generator Noise source	Generator Number				
	1	2	3	4	5
Generator - casing	E1	E1	E1	E1	E1
Generator - Air Inlet	M3	M3	M3	M3	M3
Generator - Exhaust	M3	M3	M3	M3	M2
Generator - Lube Oil Cooler	-	-	-	-	-
Generator - Cooler Fan	C2	C2	C2	C2	C2
Generator - Cooler Fan	C2	C2	C1	C2	C2
Generator - Cooler Fan	C3	C3	C2	C2	C3
Generator - Cooler Fan	-	C2	-	-	-

5.1.2 Design noise limit: 30 dB(A)

The calculation was run many times to seek the global optimum, however the results did not converge to a solution that may have been the lowest possible minimum cost. The total costs for the four best results were:

- $651,300
- $645,400
- $644,100
- $638,200

The selected noise control treatments for the lowest cost result of $638,200 are shown in Table 7.

Table 7 – Noise mitigation scheme for 30 dB(A) limit, EA method

Compressor Train Noise source	Compressor Train Number						
	1	2	3	4	5	6	7
1st stage LP Screw Compressor	E1	E2	E1	E2	E2	E2	E2
2nd Stage HP Screw Compressor	E2	E2	E1	E2	E1	E1	E2
Electric Motor - LP Screw Compressor	-	-	-	-	-	-	-
Electric Motor - HP Screw Compressor	-	-	-	-	-	-	-
Fan Cooler	C2	C1	C2	C2	C1	C1	C2
Fan Cooler	-	C2	C2	C2	C2	-	C2

Power Generator Noise source	Generator Number				
	1	2	3	4	5
Generator - casing	E2	E1	E1	E1	E2
Generator - Air Inlet	M1	M2	M2	-	-
Generator - Exhaust	M2	M3	M2	M2	M2
Generator - Lube Oil Cooler	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	C2

5.2 SoundPLAN calculation results

5.2.1 Design noise limit: 28 dB(A)

The noise mitigation scheme designed by the SoundPLAN Expert System Industry optimisation module is shown in Table 8. The total cost of noise control proposed by the SoundPLAN software was $1,423,600.

Table 8 – Noise mitigation scheme for 28 dB(A) limit, SoundPLAN method

Compressor Train Noise source	Compressor Train Number						
	1	2	3	4	5	6	7
1st stage LP Screw Compressor	E1	E1	E1	E1	E1	E1	E1
2nd Stage HP Screw Compressor	E1	E1	E1	E1	E1	E1	E1
Electric Motor - LP Screw Compressor	-	-	-	-	-	-	-
Electric Motor - HP Screw Compressor	-	-	-	-	-	-	-
Fan Cooler	C2	C2	C2	C2	C2	C2	C2
Fan Cooler	C2	C2	C2	C2	C2	C2	C2

Power Generator Noise source	Generator Number				
	1	2	3	4	5
Generator – casing	-	E1	E1	E1	E1
Generator - Air Inlet	M4	M4	M4	M4	M4
Generator - Exhaust	M4	M4	M4	M4	M4
Generator - Lube Oil Cooler	-	-	-	-	-
Generator - Cooler Fan	C2	C2	C2	C2	C2
Generator - Cooler Fan	C2	C2	C2	C2	C2
Generator - Cooler Fan	C2	C2	C2	C2	C2
Generator - Cooler Fan	C2	C2	C2	C2	C2

It can be seen in Table 8 that the SoundPLAN module has applied the same noise control treatment to almost all of the noise sources, which alludes to the basis of the optimisation algorithm’s decision process as discussed earlier in section 2.2.

5.2.2 Design noise limit: 30 dB(A)

The total cost of noise control proposed by the SoundPLAN Expert System Industry software module was $666,800.

Table 9 – Noise mitigation scheme for 30 dB(A) limit, SoundPLAN method

Compressor Train Noise source	Compressor Train Number						
	1	2	3	4	5	6	7
1st stage LP Screw Compressor	E1	E1	E1	E1	E1	E1	E1
2nd Stage HP Screw Compressor	E1	E1	E1	E1	E1	E1	E1
Electric Motor - LP Screw Compressor	-	-	-	-	-	-	-
Electric Motor - HP Screw Compressor	-	-	-	-	-	-	-
Fan Cooler	C2	C2	C2	C2	C2	C2	-
Fan Cooler	C2	C2	C2	C2	C2	C2	-

Power Generator Noise source	Generator Number				
	1	2	3	4	5
Generator - casing	-	-	-	-	-
Generator - Air Inlet	M2	M2	M2	M2	M2
Generator - Exhaust	M4	M4	M4	M4	M4
Generator - Lube Oil Cooler	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-
Generator - Cooler Fan	-	-	-	-	-

Similarly to the results discussed in section 5.2.1, it can also be seen in Table 9 that the SoundPLAN module has applied the same noise control treatment to almost all of the noise sources, which alludes to the basis of the optimisation algorithm's decision process as discussed earlier in section 2.2.

5.3 Summary of results

A summary of the results from the different calculation runs is shown in Table 10.

Table 10 – Summary of optimised noise control treatment schemes

Design noise limit	SoundPLAN	Evolutionary Algorithm	Cost difference
28 dB(A)	$1,423,600	• $1,387,600 • $1,368,400 • $1,366,600 • $1,366,400	• 2.5% • 3.9% • 4.0% • 4.0%
30 dB(A)	$666,800	• $651,300 • $645,400 • $644,100 • $638,200	• 2.3% • 3.2% • 3.4% • 4.3%

As shown in Table 10, the Evolutionary Algorithm was able to develop more cost-effective noise mitigation schemes than the scheme proposed by the SoundPLAN optimisation software module. The cost savings achievable using the EA method over the SoundPLAN module were found to be up to 4 percent.

6. Discussion

With numerous noise sources and several noise treatment options available for each source, the number of combinations of potential noise treatment schemes is too large for manual calculations to achieve within a reasonable time frame.

Engineering optimisation techniques are able to devise noise mitigation schemes with the specific aims of just meeting the noise limits while at the same time minimising the total cost of noise control treatments.

The use of appropriate engineering optimisation techniques can achieve very good results by producing design schemes that will usually achieve close to the global optimum minimum total cost. The successful employment of engineering optimisation tools requires knowledge of their function and limitations in order to select the appropriate optimisation method and set up the calculations to best effect.

The two optimisation methods investigated were found to produce similar results. The Evolutionary Algorithm method yielded marginally lower total costs than the SoundPLAN software optimisation module. It is conceivable that in different circumstances the evolutionary algorithm might yield substantially lower total costs than the SoundPLAN software.

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