SIMPLIFICATION IN ENGINEERING: CONTRIBUTING REAL VALUE

ABSTRACT

Growing populations across the globe have ever-increasing needs for new products. These needs are addressed by engineers applying scientific knowledge to create new solutions. But engineering processes are not always successful. Engineers need to guard against focusing solely on the technical content of their work. They must simplify their processes, methodologies and products to ensure that their efforts contribute real value to society. This article explains how simplification can be used in the engineering process. It is shown how a simplified message can be used to motivate South African households to save energy. Another example illustrates how savings can be realised on intricate compressed air installations using simplifying assumptions.

1. INTRODUCTION

World populations are growing at an alarming rate [1]. Unsurprisingly, this results in an exponential growth in human needs to be fulfilled. These include basic needs such as clean water, secure food supplies, shelter, safety, readily available energy, etc. But it also implies novelties that have not been available before, such as lightning-fast communication, trendy entertainment, etc. These needs must all be addressed by means of limited resources, while ensuring a minimum negative impact on the natural environment [2].

Various parties are involved in this worldwide pursuit for solutions, including activists, politicians, business people, financiers, etc. Although these groups have well-defined interests, the discipline best-suited to contribute on a technical level, is engineering. This follows, *inter alia*, from the definition of an engineer. Engineering can be defined as a process of using scientific knowledge and tools to produce practical solutions [3]. One test for good engineers is therefore whether their solutions or products contribute real value to people’s lives [4]. But why does it seem that many products or solutions fail in this regard?

There are many examples of such failures. IBM Computers became one of the largest companies in the world, presenting the world with various technological feats [5]. But the company was nearly permanently ruined when it did not adapt quickly enough to changing market conditions. Competitors provided the market with cheaper and more advanced desktop computers and software [6].

Locally, our defence industry experienced the same misfortune. Market commentators agree that South Africans created highly innovative products in the "sanction era" [7]. Unfortunately, it failed to capture world markets convincingly [8]. The scaling down of the Pebble Bed Modular Reactor (PBMR) Company seems to be another disappointment. Despite the many advantages of their developments [9], and having been at the forefront of new technology, this company has been forced to reduce its workforce due to limited funding [10].

There are numerous explanations for these and similar failures. These include politicking, lack of leadership and vision, in-fighting, poor planning, etc. [11]. But engineers must also carry part of the blame. Engineers sometimes tend to focus on their technical innovations, new technologies and product details [12]. In the process they sometimes lose sight of the ultimate goal of creating practical solutions for non-practical people [13], [14]. One way to address this problem is to spread the message of ***simplifying***.

2. SIMPLIFICATION AS ENGINEERING TOOL

Simplification can be applied to all aspects of the engineering process. Engineers need to spend time and effort understanding market needs, requirements and accompanying limitations. They also need to be aware of all the hurdles as well as the roleplayers who may attempt to derail an engineering process. This has serious implications, as engineers are normally regarded as technically-minded people first and foremost [14].

Engineers need to consider how their proposed solutions will interact with people. This means that when new technologies are developed, attention must be focussed on creating simplified solutions rather than intricate or technically-advanced products.

This approach has been used with great success by various groups. One of the most recent examples is Apple Inc, who does not always present the market with world-firsts. But their products such as the iPhones are easy to use and have simplified designs [15]. Their success with this approach is proven with the rise in market capitalisation of the company. Apple has grown to become one of the largest companies in the world, surpassing even Microsoft [16].

Simplification has another consequence. It implies that an "unfinished" product (i.e. a product that has not necessarily followed all the classic development steps or cycles) released quickly into the market is usually better than a seemingly-perfect innovation released too late. Products released into the market first, will probably be market leaders for a significant period of time [17]. Being a market leader has important advantages. For example, the market leader has the best opportunity to fine-tune designs into better products.

Microsoft is a good example of adopting these simplification practices. Many experts agree that their products are not necessarily the best, the most stable or technically advanced [18]. Yet they have a philosophy of getting products into the market as quickly as possible and allowing users to identify problems and additional needs. This approach has helped Bill Gates to become one of the richest people in the world [19].

This way of thinking is essential in South Africa and, in particular, our local engineering fraternity. We have significant local needs with limited resources. Our needs can be addressed efficiently by applying simplification to our engineering processes and really make a difference to people's lives. The rest of this article shows how this approach has been successfully applied to South African energy savings.

3. ENERGY SAVINGS IN DEVELOPED HOUSEHOLDS

3.1. PREAMBLE

Energy is an important topic worldwide. Many countries have initiated awareness campaigns to promote energy conservation [20]. A number of these campaigns focus on the domestic sector. This is beneficial as people who save energy at home are also likely to do so at work. Furthermore, children who learn to save energy at home will be more likely to continue doing so, once they become leaders of commerce and industry. They will also encourage others to do the same. Residential energy saving campaigns will therefore have a wide impact [20].

One problem with many of these campaigns is the complex messages that it tries to convey. The public will not be convinced to change wasteful habits unless they are motivated to do so with a single, easy-to-understand message. The most effective motivator is probably direct financial benefit. Energy savings should therefore be expressed in monetary terms [20].

Factors such as inflation and rising energy costs make monetary savings, calculated at a specific date, redundant within a relatively short time period. This means that South African campaign material may become less useful within a year. A simplified solution is to present savings in an equavalent monetary unit. One idea for such a monetary unit is a fast food hamburger. This unit is easily understood by people of all ages and cultures [20].

3.2. IMPORTANT ASSUMPTIONS AND LIMITATIONS

Assumptions are essential in the process of simplification. For example, determining typical savings for a household will be difficult without simplifying assumptions regarding the number of occupants, household appliances and its usage patterns, sizes of equipment, etc.

The first assumption takes into account that households in the developed sector of South Africa use electricity for more than 93% of their energy requirements [21]. Therefore only electrical saving suggestions are included. Furthermore, energy savings suggestions may result in large monetary savings but may be difficult to implement. The time, money and effort needed to realise a suggestion together with the monetary savings must be taken into account. Therefore only easy-to-implement savings suggestions with a high saving potential will be used [22].

Determining ease of implementation of energy saving suggestions is very subjective. Each person is unique and has his or her own preferences. Therefore people may differ about the ratings for the suggestions. Once again, it was envisaged to provide suggestions that will suit most people [22].

The study was conducted using an average monthly electrical energy consumption of 1,150 kWh [21]. This is a relatively low consumption but ensures that savings suggestions are conservative. It is therefore incorrect to add all the savings to obtain a total monthly saving. This total could be more than the assumed monthly energy account.

The household considered in this study would typically consist of two adults and two children, in a medium to upper income bracket. This is why suggestions involving a swimming pool, dishwasher, tumble-drier and other luxury equipment are included. Usage patterns of household equipment were found in references [23] and [24]. From this information it was possible to predict realistic savings for the given energy saving hints.

The rest of the assumptions needed for the calculations and simulations are not given here. These, as well as the details of the calculations, are given in reference [20]. Only the final results are presented here.

3.3. WATER HEATING

The hot water system of an average household in the developed sector accounts for 40% of the household's annual energy consumption [25]. Savings from the hot water system should therefore have a noticeable effect on the monthly electricity account. The suggestions providing the highest potential savings are shown in Table 1.

Table 1: Water heating

Saving Suggestions	Savings per year [kWh] *	Hamburgers per year **
Showering instead of bathing	1,000	35
Setting geyser thermostat to 60 °C	700	25
Fixing leaking taps	500	16
Using the cold water tap	500	16
Insulating the geyser and pipe	300	10
Switching geyser off when away ***	300	10

* Potential savings if these actions were not implemented in the past.

** Number of hamburgers that can be bought with the money saved on energy in one year.

*** If the home-owner is away for one month a year.

3.4. SPACE HEATING

An estimated 10% of the annual domestic energy consumption is due to interior heating [25]. The five most appropriate saving suggestions are listed in Table 2 together with potential savings. Saving suggestions for cooling were omitted because only 3% of households have air-conditioners [25].

Table 2: Space heating

Saving Suggestions	Savings per year [kWh] *	Hamburgers per year **
Insulating the roof	1,350	46
Closing doors and windows	550	19
Using warm or electric blankets	500	16
Using curtains and pelmets	350	12
Switching heaters off selectively	250	8
Not overheating rooms	200	7

* Potential savings if these actions were not implemented in the past.

** Number of hamburgers that can be bought with the money saved on energy in one year.

3.5. KITCHEN AND LAUNDRY

Various energy-consuming appliances are used in the kitchen and laundry. Significant savings can be made if these appliances are used correctly. Table 3 lists these savings as rated according to their relevance for a household.

Table 3: Kitchen and laundry

Saving Suggestions	Savings per year [kWh]*	Hamburgers per year**
Using small appliances	1,300	44
Using full loads in equipment	900	31
Sun-drying washing	800	27
Using economy cycles	650	19
Checking door seals of fridge and freezer	400	14

* Potential savings if these actions were not implemented in the past.

** Number of hamburgers that can be bought with the money saved on energy in one year.

3.6. OTHER ENERGY-CONSUMING APPLIANCES

This section considers electrical appliances which were not mentioned earlier. These are lights, small appliances, swimming pools, and power tools. Saving suggestions for this category are listed in Table 4.

It is important to remember that not every household has all the above-mentioned appliances. However, notable savings can still be achieved by implementing the relevant suggestions.

Table 4: Household appliances and lighting

Saving Suggestions	Savings per year [kWh]*	Hamburgers per year**
Installing movement sensors to reduce lighting hours	2,500	86
Servicing pool pump and cleaning filter	1,300	44
Reducing cycle time of pool pump	700	25
Switching off appliances and lights	400	15
Using compact fluorescent lighting (CFLs)	350	12

* Potential savings if these actions were not implemented in the past.

** Number of hamburgers that can be bought with the money saved on energy in one year.

3.7. DESIGNING OR BUYING A HOUSE

Energy savings in existing houses focus on the home owner and his family who will have to change wasteful habits and perform possible retrofits. However, when designing a new house, methods to save energy can be considered beforehand. These methods are given in Table 5.

Table 5: Designing or buying a new house

Saving Suggestions	Savings per year [kWh]*	Hamburgers per year**
Insulating the roof	1,350	46
Insulating geyser and pipes. Installing short pipes and setting the thermostat at 60 °C	1,150	40
Fitting single bulbs and fluorescents (CFLs)	700	24
Draught-proofing the house	600	21
House facing north	350	12

* Potential savings if these actions were not implemented in the past.

** Number of hamburgers that can be bought with the money saved on energy in one year.

3.8. CLOSURE

National campaigns are needed to change the public's attitudes towards more energy efficient lifestyles. These changes will only be sustainable if people are kept informed about the monetary benefits. This section showed that these saving benefits can be presented in simplified equivalent units such as take away hamburgers. The advantage of this approach includes its independence on inflation and the fact that the message is understandable to people of all ages and cultures.

4. SIMPLIFIED APPROACH TO REDUCE MINE COMPRESSED AIR ENERGY

4.1. PREAMBLE

More than 14% of the electricity generated by Eskom is sold directly to the mining sector [26]. Investigations at various South African mines indicated that compressed air is responsible for as much as 20% of a mine's total electricity costs [27]. This means that South African mine compressors use roughly the same amount of electrical energy than the City of Cape Town.

Optimising compressed air systems on mines can therefore contribute substantially to much needed electrical energy savings. This section describes how such savings were achieved by using a simplified engineering approach.

4.2. REDUCING ELECTRICITY CONSUMPTION USING A SIMPLIFIED APPROACH

Compressed air systems on typical South African mines consist of intricate pipe networks [28]. Figure 1 shows a diagram of a typical distribution network on a single underground level. Keep in mind that there may be more than 20 such levels for one mine shaft. Matters are complicated even more when a number of shafts are linked on the surface to a compressed air supply ring. Air supply and demand networks can therefore be fairly complex.

Analyses of these networks are relatively difficult. It is further hampered by the difficulty in obtaining accurate working drawings of all equipment, including pipe sizes, locations, condition, etc. Detail simulations of these networks and all the components can be a daunting and time-consuming, if not an impossible, task. A simplified approach is required that will give relatively quick answers to the question of potential energy savings.

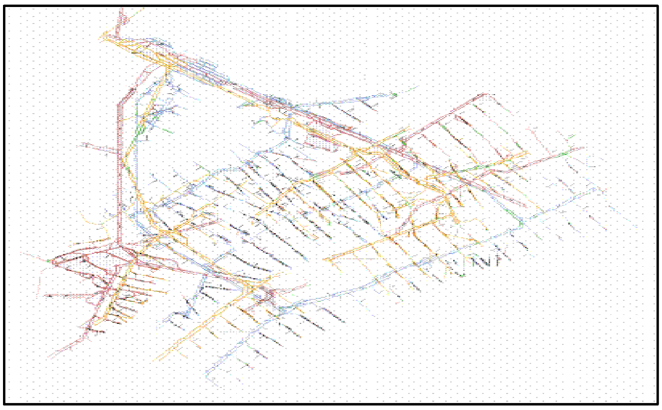

Figure 1: Complex network of compressed air on a single underground level on a typical gold mine

The first step will be to simplify the engineering view of the compressed air system. Instead of focusing on all the detail elements and their interactions, it could rather be regarded as a single pressurised system with thousands of leaks. Some of the leaks are productive air leaks, such as those used by pneumatic equipment including drilling, loading, etc. Other leaks are non-productive and may consist of ill-fitting couplings, valves left open, etc.

Compressors keep the system at a pre-set pressure. This pressure is the driving force of the pneumatic equipment linked to the system. If the number of leaks can be reduced, compressor power can be reduced because less air needs to be pushed into the system. The next option is to save compressor power by controlling the system at a reduced pressure. Naturally this impacts on the pneumatic equipment. Some will have to be changed or replaced as the lower supply pressure will make them ineffective.

This simplified understanding leads to the following systematic approach to minimise compressed air energy consumption on a mine:

i. controlling and measuring the compressed air network;
ii. providing ultra-control in the work areas;
iii. reduce pressure to 350 kPa;
iv. reduce pressure further to 150 kPa; and
v. switch off all compressors.

The first two steps enable the mine to distribute only the required quantities of air, at the appropriate pressure, to those locations where it is really needed. Savings are realised by curbing excessive pressures at some places and closing flows (or leaks) to areas where compressed air is not required. The third and fourth steps decrease the pressure of the system with the resulting saving on compressor power. The last step involves a complete changeover to alternatives other than compressed air. These five steps will now be discussed in more detail.

4.3. CONTROLLING THE COMPRESSED AIR NETWORK

An example of a typical network control system is shown in Figure 2. Control valve units are installed at strategic locations which often include one or more units on each underground mining level. These valves can regulate the flow of compressed air and are connected to a centralised control system.

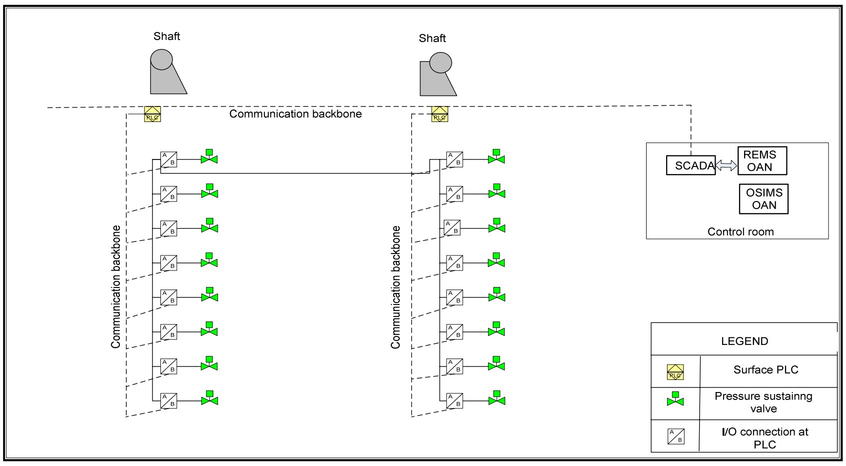

Figure 2: Simplified view of the control system of a mine compressed air network

The control valve restricts the airflow to the controlled area, which is typically a mining level. Different operational modes are used depending on working schedules and the activity in the controlled area. Peak production periods will, for example, require maximum unrestricted flow that will require a valve to be fully open.

The implementation of network control at South African gold mines has resulted in savings that vary between 10% and 35% [29]. Figure 3 shows the results for a specific project. Energy consumption is plotted over an average 24-hour typical working work day at the mine. The red curve indicates the baseline power consumption of the compressors before savings actions were implemented.

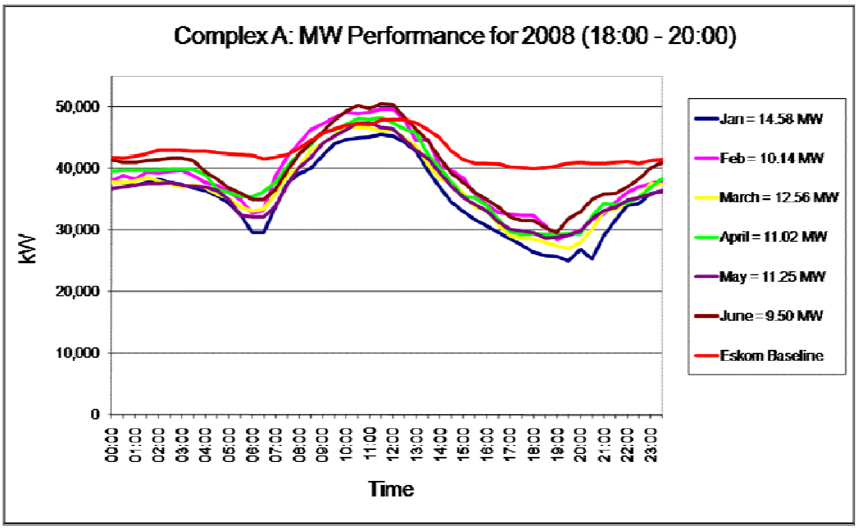

Figure 3: Example of savings realised through control of a simplified mine network

The monthly coloured lines show that no attempt is made to save compressor power during the middle of the day as this coincides with the main production period of the mine. Pneumatic equipment such as rock drills, must then work at maximum pressure. Before and after the drilling period the pressure of the system can be reduced. This is in conjunction with restricted air flow to the different mining levels.

The savings illustrated in Figure 3 are approximately 50 MWh of energy per day. This implies that improved control on this mine compressed air ring provides savings equivalent to the average electrical power requirement of a town such as Cullinan.

4.4. ADVANCED NETWORK CONTROL

Air supply lines to mine working areas are continuously being lengthened as production areas become deeper and further away from the shaft. Repairing the leaks in these pipe lines is a time-consuming and apparently never-ending task [30]. A different approach to reduce the effects of compressed air leaks in these sections is to isolate the compressed air supply during non-production times. The installation of section isolation valves that close automatically during non-production times will eliminate leaks downstream of the valve during periods when compressed air is not required.

Eliminating leaks during blasting, which takes place over a period of 8 hours a day, could reduce energy consumption by at least 10% over this 8-hour period. An additional estimated saving of 3.3% could be realised if these valves were installed and all other mainlines were maintained in a leak-free condition. The network control valves will provide a saving of 20% and the isolation valves 3.3%, giving a combined total of at least 23.3% in energy savings [31].

4.5. REDUCING RING PRESSURE TO 350 KPA

The system pressure is dictated by the equipment with the highest pressure requirement. Therefore, total system pressure can only be reduced if high-pressure equipment is replaced with equipment requiring lower operating pressures.

One such example is the pneumatic loaders, shown in Figure 4, used for moving blasted ore. Some loaders operate at high pressures of 450 kPa or even higher. These loaders need to be replaced with low-pressure units capable of operating at 350 kPa. Pneumatic rock drills may also have to be replaced with newly-developed electric drills.

Figure 4: Pneumatic loader (Trident SA, "EIMCO 26B ROCKERSHOVEL", from http://www.tridentsa.co.za - July 2010).

When the ring pressure is reduced, the results will typically look like those presented in Figure 5. Once again the red curve indicates the baseline energy consumption before the pressure was reduced. The other lines represent the average monthly consumption as a result of the lower pressures. An energy saving of approximately 15 MW, or 35% of the baseline, is achieved. This saving is sufficient to supply nearly 10,000 average-sized houses with electricity. Should this saving be repeated on all mine compressors, it will be enough to supply electrical energy to a city such as Bloemfontein.

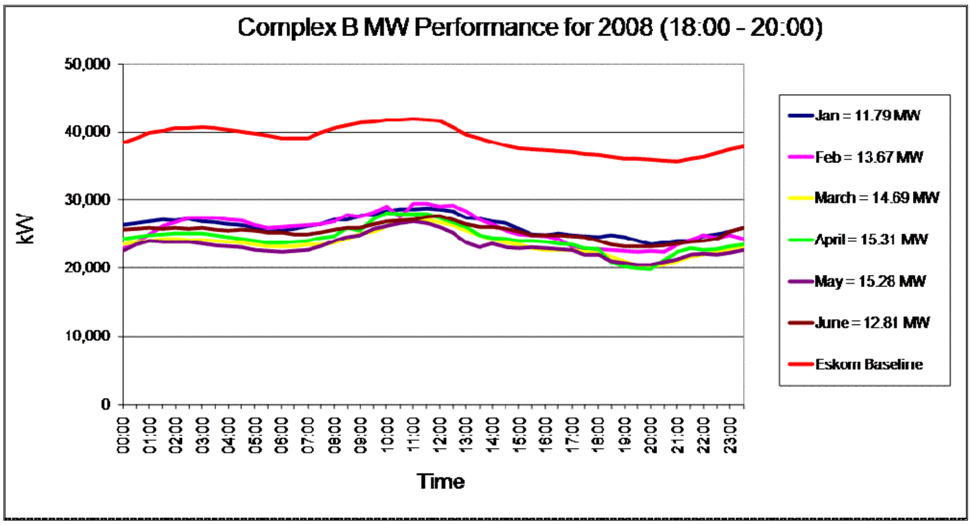

Figure 5: Example of savings realised by reducing compressed air system pressure

4.6. REDUCING RING PRESSURE TO 150 KPA

Ring pressure can be reduced even further by replacing all compressed air equipment such as pneumatic loaders, drills, loading box cylinders, agitation mechanisms, etc. Newly-developed hydraulically powered cylinders can replace pneumatically powered loaders and cylinders. Air agitation can be replaced by mechanical agitators.

Compressed air at this low pressure will still be required for ventilation and safety reasons. Refuge bays are provided as a safe haven for workers in the event of underground fires. Compressed air is supplied to the refuge bays to provide fresh air to the occupants in the event of an emergency. Keeping the refuge bays under positive pressure also restricts smoke from entering in the event of fire.

4.7. REMOVING COMPRESSORS

Total elimination of the compressed air is the next step. Compressed air used for ventilation purposes will have to be replaced by electric fans and other localised cooling equipment. Refuge bays will have to be supplied with Self Contained Self Rescuers (SCSR). These devices are designed to operate for relatively short periods only but still allow sufficient time for workers to walk to safe locations in the event of an emergency. More research and development for long-lasting alternatives are required.

4.8. SUMMARY OF RESULTS

Changes to the compressed air system of a mine may have a large financial impact. Some results of cash flow analyses applicable to a specific mining group are summarised in Figure 6. This figures compares the nett cash flow for implementing the five different energy saving steps. Some options will require complete re-equipping of existing infrastructure of a large mining complex and are just too costly to implement.

Reducing the ring pressure to 350 kPa appears to be the most lucrative option in the long term, but also has a relatively long payback period. Only if a mine still has a long production lifetime could this option be considered. Unfortunately this only applies to a few South African mines. Many operations with large compressed air systems, typically found on the gold mines, are close to the end of their productive lives [32].

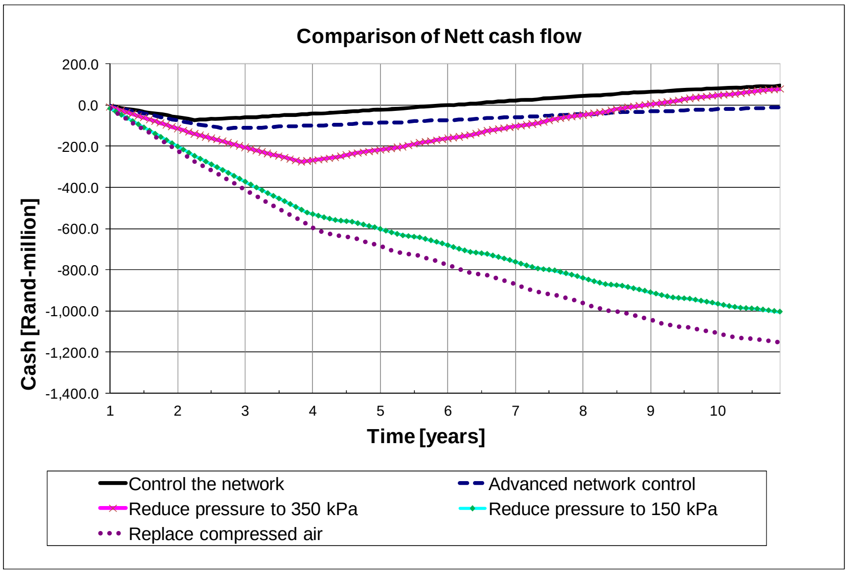

Figure 6: Nett cash flow for the different initiatives

5. CONCLUSION

Engineers play a vital role in supplying the world with solutions and products. But it is crucial that engineers make bona fide contributions. One way to ensure this is to employ simplification in the engineering process. Two case studies were presented where simplification was used to address specific needs. Residential energy savings can be realised by changing attitudes of home dwellers. It was shown how a simplified message can assist in attaining these goals. In a similar manner, savings in the mining sector can also be addressed through a simplified approach to compressed air systems.

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