Disposal of latrine waste: Is biogas the answer? A review of literature

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Abstract

Emptying pit latrines is a major problem in urban sanitation in low-income countries. Besides the difficulty of taking the partially decomposed faecal matter out of the pit, the sludge has to be disposed of. Rather than treating it as a waste, this could be seen as a resource. This paper looks at the potential of using the sludge for the production of biogas.

1. Disposal of latrine waste – the issues and solutions

On site sanitation systems have long been used in the developing world. "*Increasing population density, lack of technological options and meagre resources available to local authorities*" (Thye et al 2009) has led to an increase of research into latrine emptying. Practices such as "*covering a full latrine and relocating the superstructure*" (Boot, 2007) are not feasible or sustainable in many situations, therefore emptying and disposal procedures are seen as the answer.

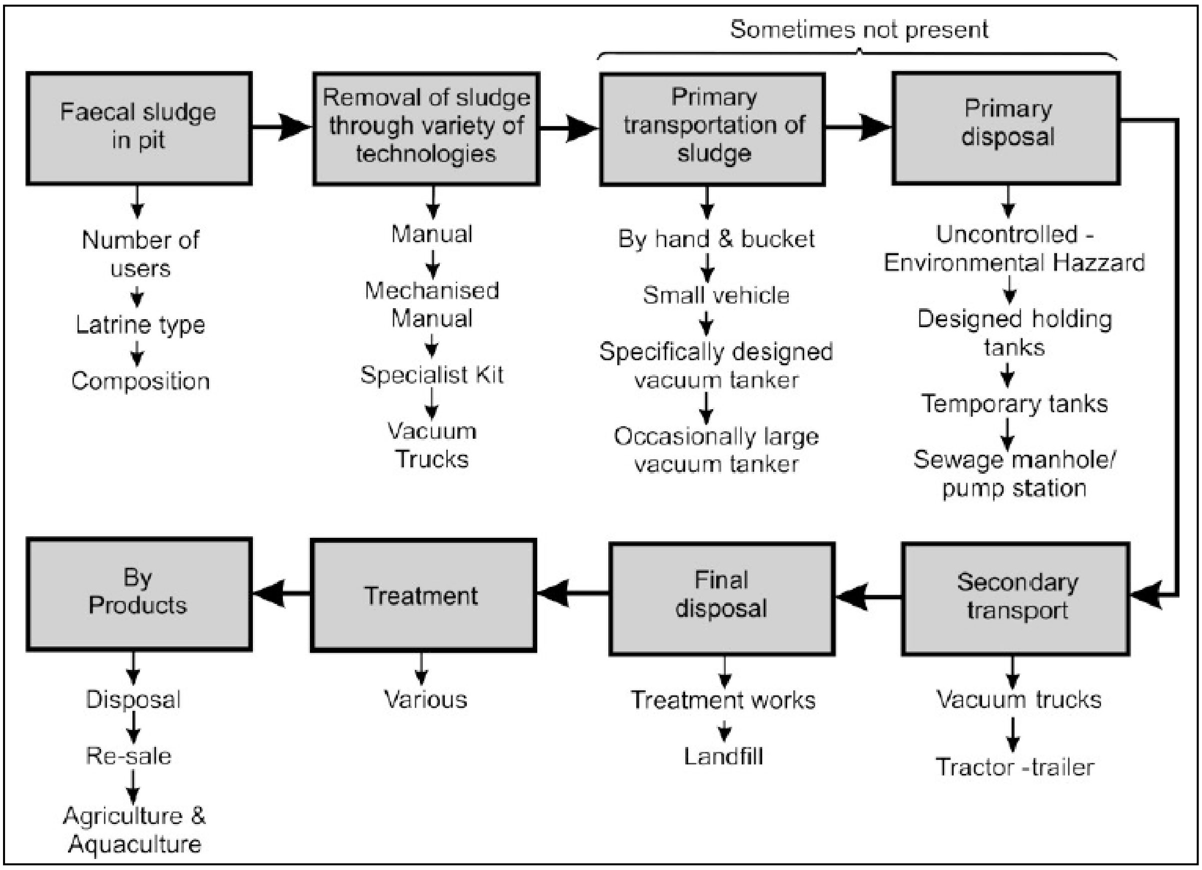

Figure 1 Faecal Sludge Management Cycle - (Boot 2007)

1.1. Disposal options

Onsite direct burial

This is usually only feasible with smaller amounts of sludge, which is "*placed in layers … then covered with … soil before the next layer of sludge is added*" (Scott & Reed, 2006) into a trench. Logistically this carries many benefits, cutting down on haulage and decreasing the complexity of transfer for manual emptying, but it needs spare land, which is in short supply in dense, large communities.

Discharge into sewer or centralised treatment works

If the sludge is relatively liquid, it can be discharged into a sewer or treatment works. However, as outlined by Hasan et al (2004) discharging into sewers can be problematic as they are often blocked. Also piped networks are extremely expensive and difficult to build and maintain that is why the number of them in the developing world is low. Discharging into centralised treatment works often suffers from extensive haulage costs due to the large distances between the community and the works (Boot 2006). The transport needed, for example a tanker, are expensive to buy and maintain and can lead to large tariffs for the user, that they cannot pay. This often leads to the operator practising indiscriminate dumping to cut their costs. The environmental and health impacts of this are huge - dependent on the location, Strauss et al (2006) states that "*if one vacuum tanker indiscriminately dumps faecal sludge into the environment it is comparable to 5,000 people defecating openly.*" In many developing countries is also the state the treatment works is often poor. In Accra, Ghana, Boot (2006) points out that the facilities were in a "*poor state of disrepair*" with a large proportion of the stabilisation ponds out of use. Lack of skilled workers and cost of maintenance often result in the failure of treatment works, making a more decentralised option more attractive.

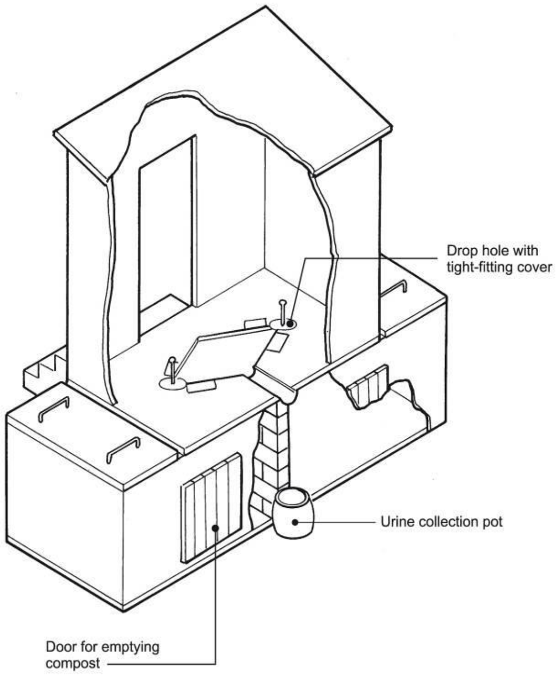

Figure 1 An example of a composting toilet - (WEDC)

Composting

In many countries such as Ghana, Haiti and South Africa (Scott & Reed, 2006) co-composting is practised where the faecal sludge is mixed with other organic material such as vegetable waste to help the anaerobic digestion process to take place. This must take place in a sealed container with a vent to let the methane escape or issues will arise due to its flammable nature. The residual can be used as a soil conditioner. Other composting methods such as composting toilets are hugely popular with resource orientated organisations such as Ecosan.

These technologies work using aerobic digestion. They remove the need for transportation of the faeces to another container for the digestion to take place removing the health issues surrounding contact with fresh faeces. The vent allows the flammable gas to escape whilst a drain allows any excess moisture to leach back into the ground. After around 6-12 months (Envirolet, 2009) the residual can be removed. They do not offer a solution to the issues surrounding *existing* onsite sanitation technologies, as every pit would have to be replaced. Any gas produced is vented away. Many resource-orientated organisations do not see a use for this gas, placing most of their argument on gaining a soil conditioner at the end of the cycle. The author identifies this as a waste and identifies another method of disposal; Biogas Generation. This report aims to assess the feasibility of this technology as a solution to the issues surrounding disposal and how it could be implemented and managed.

2. Biogas

There are differing definitions for Biogas such as Itodo and Phillips' (2001) "*a methane-rich gas that is produced from the anaerobic digestion of organic materials in a biological-engineering structure called the digester*." Also Bates' (2007) description of, "*a gas mixture comprising around 60% methane and 40% carbon dioxide that is formed when organic material, such as dung or vegetable matter are broken down by microbiological activity in the absence of air, at a slightly elevated temperature*." Also known as "*swamp gas, marsh gas and gobar gas*" (Hilkiah Igoni et al, 2007), biogas is a "*clean cooking and lighting fuel*" (Bates, 2007).

Table 2 Biogas Composition (Yadava & Hesse, 1981)

Substances	*Symbol*	*Percentage*
Methane	CH_4	50 – 70
Carbon Dioxide	CO_2	30 - 40
Hydrogen	H_2	5 – 10
Nitrogen	N_2	1 – 2
Water Vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Table 1 Gas Production potential of various types of dung (Updated Guidebook on Biogas Development-Energy Resources Development

Types of Dung	*Gas Production / kg dung (m^3)*
Cattle	0.023 - 0.04
Pig	0.04 – 0.059
Poultry	0.065 – 0.116
Human	0.02 – 0.028

To produce the Biogas a feedstock material must be used such as vegetable matter and dung. However, it is the general belief that "*liquid-manure systems work best for anaerobic digestion in the production of biogas*" (Hilkiah Igoni, et al, 2007). The yield from human waste is low in comparison to other manures, but the gas gained should be seen as a bonus; the main purpose is an alternative disposal method, also "*reducing the amount that would otherwise be released naturally into the atmosphere and so reduces the excessive greenhouse-effect*" (Xuereb, 1997).Other benefits of digesting human waste are:

- "*Methane being a fuel reduces the amount of wood fuel required and thus reduces desertification*
- *The waste is reduced to slurry that has a high nutrient content making an ideal fertiliser*
- *During the digestion process, dangerous bacteria in the dung are killed, which reduced the pathogens dangerous to human health*" (Bates, 2007)

These points make handling the residual easier but also in poorly ventilated homes, biogas is a "*clean fuel, thus reducing the levels of indoor air pollution, a major cause of ill health for those living in poverty"* (Bates, 2007).

2.1. Uses

The biogas can be used for cooking, lighting or heating for dwelling or water. In more developed nations such as China the technology is used to boost "*photosynthesis by increasing the carbon dioxide concentration*" (Bates, 2007) in greenhouses for agriculture, and in Finland it's even used to run cars (Hilkiah Igoni, et al, 2007). Digestion works best at an ambient temperature of around 37^{o}C. In colder climates, this is hard to achieve, so the biogas produced can heat the digester itself. Although the biogas is not gained, the disposal solution is still valid as the residual will decrease in size by around 50% making transportation easier and can be spread over farmland.

2.2. Possible Digester options

The digester provides a sealed vessel that allows input of feedstock and removal of gas, ideally being built of locally available materials. The options are outlined further below thanks to The Sustainable Development Department (1996) and Munasinghe & Wijesuriya (2007).

Table 3 Some biogas equivalents (Kristoferson & Bokalders, 1991)

Application	*1 m^3 biogas equivalent*
Lighting	Equal to 60 – 100 watt bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5 – 6
Fuel	0.7kg of petrol
Shaft Power	Can run a one horse power motor for 2 hours
Electricity	Can generate 1.25 kilowatt hours of electricity

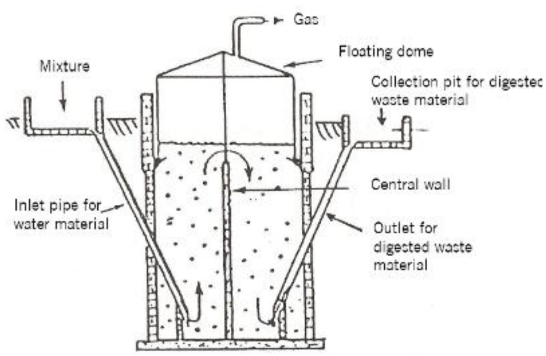

Figure 3 Floating Drum Digester - (Munasingha & Wijesuriya, 2007)

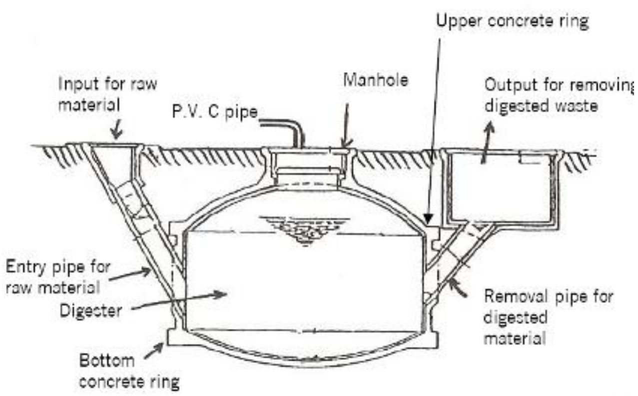

Figure 4 Fixed Dome Digester (Munasingha & Wijesuriya, 2007)

The "Floating Drum"/"Indian" Digester

Developed in 1956 the chamber is made of masonry and a steel drum placed on top to catch the biogas. The drum moves up as it fills. It requires high investment and maintenance.

The "Fixed Dome"/"Chinese" Digester

Dating back to 1936, it consists of an underground masonry compartment also known as the fermentation chamber and a fixed dome for gas storage. The single piece structure decreases the complexity of maintenance whilst still having two drains to feed waste. The life span is longer at around 20 to 50 years increasing its economic feasibility. The Gas and Agricultural Equipment Development Company (GGC) of Nepal have developed a cheaper concrete design built from this that has been around since the early 80's, showing the initial shape is tested and proven.

The Deenbanhu Model

Originally developed by Action for Food Production in 1984 to bring down costs. It proved 30% cheaper than a fixed dome design based on the Chinese Digester and 45% cheaper than the Nepalese KVIC plant. Made entirely out of masonry with hemisphere gas storage at the top and concave base working under the same principles as a normal fixed dome digester.

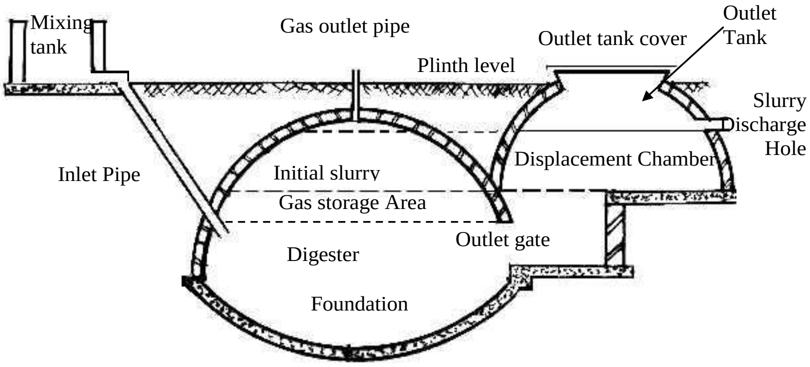

Figure 5 Deenbanhu digester - (Action for Food Production, 2000)

Other Digesters

There are a number of smaller less popular technologies often used in emergencies and also advanced technologies not suitable for this report. The *bag digester* consists of a long cylinder made of PVC developed to overcome the issues with brick and metal such as corrosion. It was found they were only useful where PVC and welding facilities were hard to achieve in a low-income situation. Yen-Phi et al (2009) also outlines how Plastic Bio-Digesters suffer from lower quality residual. The plug flow digester builds on the idea of the bag digester by using a trench much longer than it is wide or deep then lining it with concrete or an impermeable membrane. A cover is then provided as gas storage.

3. Assessing the technology

The development of household biogas technology is "*over 60 years old in India*" (Myles, 2001) and is used widely throughout countries such as China, Thailand, Latin America and Southern Africa. In China, by 2007 there were "*26.5 million biogas plants, whose output had reached 10.5 billion m^3*" (Chen et al, 2009). Household biogas generators have been accepted because the connection between the latrine and the digester requires no contact with the waste, bypassing any taboos. Implementing the technology in a more community-based situation may have its limits but there is evidence that Community Biogas Plants have been implemented. The International Reference Centre for Waste Disposal (IRCWD, 1982) examines a number of areas where it has been used and identifies that community plants provide benefits including:

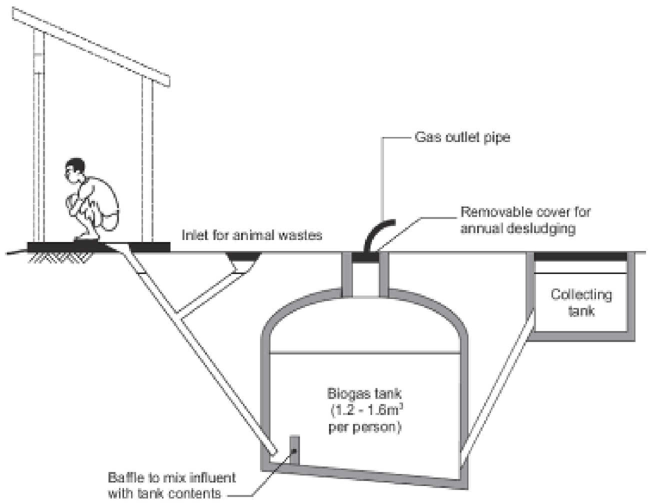

Figure 6 Insitu biogas system - (Reed & Shaw)

- Economies of Scale
- Surplus gas for income generating activities
- More efficient operation as the plant usually has a full time operator
- Equity consideration, people can work in return for gas

Striebig et al (2006) identify how Biogas technology was used for sanitation in Kigali, Rwanda on a community level and providing gas that cost the household $0.23 per person per day "significantly less than the current cost of imported oil." There are a number of examples of where Biogas technology has also been a success in institutions such as prisons in Kaski, Nepal (Aryal, 2009) and Kigali, Rwanda, where the prison holds "*5,000 people who together produce 50m3 of toilet waste per day* [producing] *a whopping 250m3 of biogas per day*" (Hartmann, 2009). Biogas has also been used widely in schools, in Maphephetheni, KwaZulu-Natal (Sibisi & Green, 2005) and Lem, Ethiopia where 7 schools with an average population of 5,500 were fitted with digesters between 2000-2002 and the technology is still working today (Worku, 2009). There is evidence out there that community or parish level digesters can work, however most of these use fresh excreta. This investigation aims to examine how using partially degraded sludge will affect the feasibility of the process.

The first step is to assess what happens to the sludge in a pit. Bhagwan et al (2008) describes "What happens in the Pit" based on findings from a Water Research Commission project (2007).

- Accumulation: Material that does not degrade or drain away builds up within the pit
- Aerobic Degradation: In the presence of oxygen and aerobic micro-organisms biodegradable material is converted to CO_2, water and cell mass. This takes place at the very top of the pit as oxygen depletes a few millimetres into the contents.
- Anaerobic Degradation with the rate affected by pH, moisture and inhibitory substances
- Physical mass transfer: the transfer of the substrate to the micro-organisms and the waste products from the organisms. Too dry and issues with viscosity and osmotic pressure arise, too wet and the substrate may begin to leach
- Leaching/draining: Depending on the rock/soil type and the height of the water table, liquid may percolate out of the pit leading to dryness or water may enter the pit.
- Digestion of macro-invertebrates: Fly larvae and other worm-like invertebrates have been observed in pits. They have two main effects: they digest material and their movement allows aeration of a thicker layer leading to increased aerobic degradation. Fly larvae usually signal poor construction practices and can lead to severe health issues

Sludge will be partially degraded upon emptying therefore decrease the methane yield.

3.1 Social and Cultural issues

Myles (2001) indentifies that socio-cultural issues must be addressed before the implementation as there is a "*good chance of failure, as these technologies are new and alien to rural people*." It is "*extremely difficult to achieve change in excreta disposal practices as they are part of the basic behavioural pattern of a community and are not readily modified*" (Feachem & Cairncross, 1978). Chaggu et al (2002) identify in Dar-es-Salaam that there is a lack of understanding why the disposal system has to be changed because of the "*lack of perceived benefits*" (IRCWD, 1982) biogas technology has. The low education level results in "*inadequate financial resources*" (Chaggu et al, 2002) so the priority is not a good excreta disposal when there is competition for financial resources. This poor education level leads a low level of involvement (Strauss et al 2002) and without involvement, skills cannot be passed on. This lack of knowledge can lead to an unwillingness to use the by-products (Strauss & Montangero, 2002) decreasing the value. Bates (2007) also indentifies the importance of community involvement to develop a sense of ownership because without it people will not feel obliged to maintain the plant.

A concern is religious issues over human excreta. Night soil workers carry a stigma, Eales (2005) explains that in Kibera residents see the job as illegal and it is therefore "*legitimate to assault those who haul stinking buckets and drums through narrow alleys.*" This leads to working at night because *who haul stinking buckets and drums through narrow alleys.*" This leads to working at night because there is less chance they will be robbed or beaten. It is not safe to work in total darkness in such a dangerous environment. Community wide education would have to combat this issue. Bates (2007) also indentifies that some communities may see the use of the gas as unacceptable. A less direct use such as heating water may be a better application in some societies. Education is also need to explain the hazards of dumping as Linares et al (1999) explains that at present there is no "*real demand for implementing effective systems for wastewater and faecal sludge management*."

There are also the health issues where "*government public health authorities often oppose excreta re-use because of the health risks involved*" (Edwards, 1985). Faecal oral transmission is one of the main causes of disease in developing countries. Bhagwan et al (2008) states that it takes 1 year retention within a pit for the pathogens to be eliminated (with the exception of helminthes eggs). It is highly likely the sludge within the pit will still contain pathogens upon emptying so it is paramount that the night soil workers are provided with the correct equipment and given training.

3.2 The economic argument

The initial issue (Bates 2007) is the high set-up costs of a biogas system. There are labour and material costs associated with the digesters but also the construction of the gas delivery method. Parkinson et al (2003) indentifies that although decentralized systems do reduce the cost of investment in comparison to large complex centralized treatment infrastructure, the majority of government agencies lack the funds to invest, so it is usual to look to the private sector (Bates, 2007), higher levels of government (Parkinson & Tayler, 2003), or overseas agencies (Myles, 2001) to help fund the project . Some labour costs can be decreased by involving the community who will benefit from the system providing a sense of ownership and improved maintenance. Bates (2007) describes how the system should be sold as a "win-win" situation to government organisations due to the free clean energy provided and reduction in waste disposal problems.

The frequency of emptying pits will increase to make this technology feasible. Strauss et al (2002) identifies "*unaffordable emptying fees*" as a hindrance to good faecal sludge management. A number of case studies outline that current emptying causes a burden due to high tariffs. Boot (2006) explains that in Accra, Ghana the emptying systems are privately run and have no governmental control over tariffs or disposal points. Where there is little competition, the operating company charge unaffordable tariffs, whilst also cutting their own costs by not transporting to a treatment facility and just dumping it with many practising the principle of "*out of site, out of mind*" (Chaggu, et al, 2002). Increasing the frequency of emptying may be met with hostility by most users, especially those who do not have a secure tenancy agreement for their homes who will not want to invest in new wastewater practices (Parkinson & Tayler, 2003).

Some cost recovery will be gained from the biogas keeping the emptying tariffs down. Also because the frequency has increased often the volume of sludge emptied will be smaller, so again the charge will be lower, so the annual amount people pay may decrease but the number of payments will increase. This may cause issues within communities who are used to only paying when the latrine is full. Education is needed to highlight the benefits of the new payment structure.

3.3. Regulation and management

The implementation of decentralized wastewater treatment system will only be successful if the necessary knowledge and skills to operate and maintain them are "*available at the local level*" (Parkinson & Tayler, 2003). It is "*necessary to consider the development of an effective and needs responsive policy towards the issue of wastewater management*" (Hasan et al 2004). The Household Centred Environmental Sanitation approach provides a framework where the emphasis is not on waste as a burden but as a resource, decisions about implementation start at household level rising up through community making sure that all users fully understand what is happening (Schertenleib & Morel, 2003). By making the system "*locally organized and people-driven*" (Heymans et al, 2004) the community will gain the necessary skills to operate the technology without outside supervision. Government policies should enable not prescribe. It is better for the community to embrace the technology because they have been made aware of all the benefits than be told to embrace it by government. Many wastewater systems stop working due to neglect and this kind of implementation will only lead to this situation.

4 Conclusions

The cultural and institutional implications are often so large they can be the deciding factor whether the technology is a success, but the choice of technology and the way it is implemented will have social, economic and policy implications so engineers piloting such schemes need to be aware of the whole range of factors that influence success.

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