Economic, Technical and Human Implications of Lightning Protection

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Abstract Despite the significantly large number of deaths and injuries, the property loses and service downtime, lightning is not treated as a serious natural hazard in many countries of which lightning ground flash density is notably high. In this chapter, we highlight this lack of attention from both government and non-governmental sectors as a substantial barrier to curb lightning related losses. The ignorance of experts and statutory bodies that control the implementation of standards and guidelines have paved the way to the flooding of fraudulent products and technologies into the respective countries. The attitudinal issues and negligence of responsibilities of engineering and managerial capacities of both private and government sectors contributes to the mishaps and losses due to lightning-related incidents. The chapter finally discusses possible mechanisms of promoting lightning protection as business ventures in less-privileged communities by developing entrepreneurship among people having low to medium levels of technical know-how.

Keywords Entrepreneurship · Business model · Public perceptions · Economic implications · Protection measures

1 Lightning Protection as a Safety Concern

Lightning protection (LP) is a safety concern at both public and professional levels, as per the Extremely low number of papers published in safety science journals with Scopus or Web of Science database inclusion indicates that lightning has not been treated as a serious safety concern by the safety research community, both academic and professional levels, so far [1].

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Even at policy-making level, lightning has been overlooked in many countries having high lightning ground flash density. A few examples can be given in this regard from several tropical and subtropical regions;

a. The Occupational Safety and Health Act, The Government of Uganda, a comprehensive document of 89 pages released in 2006, covers almost every aspect of occupational safety risks, except lightning, a term which has not been even included once in the document. Note that Uganda has one of the highest lightning ground flash densities in the world and recorded the worst single-event lightning accident in recent history where 18 students were killed while they were inside their school building [9].
b. The Occupational Safety and Health Act, The Government of Kenya, published in 2007, a 128-page document contains the term 'chemical', 'fire' and 'lightning' at 38, 28 and zero times respectively.
c. Similar observations were made in the developed countries as well. The 416-page document, Occupational Safety and Health Regulations of Western Australia published in 1996 does not contain the word 'lightning' at least once.

The above observations depict that both political and professional/academic entities, either due to ignorance or lack of awareness, treat lightning as an insignificant safety concern at the national level. This inert and non-proactive attitude of the statutory bodies towards lightning results lack risk assessment and threat level identification concerning thunderstorm related hazards, which in turn prevents the relevant parties from taking suitable measures to curb injuries, property damage and service interruption in the respective countries. Several investigations that have been done in the last decade [2, 3, 8–11] attributed the overwhelming number of lightning-related deaths and financial losses due to the lack of awareness and educational programs on lightning safety/protection among the public.

It is advantageous to investigate the causes of the attitudes of the authorities and other concerned parties on lightning safety and protection. Intuitively, one can suggest that the sporadic nature of lightning accidents and a small number of affected people per incident may be the main reason for overlooking lightning as a serious safety threat. However, collective annual statistics, clearly delineate that lightning stands as the second or third largest threat with respect to human and animal life, properties (direct and indirect effects) and information security (power downtime, data losses, signal distortion and loss of signals etc.). It is of interest to note that countries of relatively low lightning ground flash density, but having "developed country" status (eg. Europe, and North America) pay high attention to curbing lightning threats through, standards and guidelines, safety programs, government or state legislations, and inclusion of lightning safety in school curricula, compared with the attention of less developed countries in the lightning dense geographical locations.

2 Decision Making in Adopting LP

The lack of interest in adopting appropriate lightning safety and protection measures, in many countries, is not only a drawback among the statutory bodies, policy-making institutes etc. alone. Even LP seekers at the industrial level and among the general public have similar perceptions. This fact is well supported by the research done by Gomes and Gomes [4]. As per their study, in South Asia, out of those who have adopted LP measures for their buildings, less than 1% have conducted proper risk assessment before making the decision on the type of LP system to be installed. The same percentage has been found to be 50% in South Asia and 70% in Middle East Asia, despite the fact that in these regions the reported lightning hazards is almost 20 times less than that in South Asia.

As per the same study, the questionnaire surveys reveal that the decision of adopting LP measures by the commercial and industrial sectors is based on several factors in the Asian region. The list given below depicts these reasons in descending order of the level of prominence given to each reason by the respondents.

- The lightning accident has happened at the own premises
- A marketing representative from an LP vendor has visited and persuaded them to install the LP system
- The lightning accident has happened in the neighbourhood
- Insurance companies have insisted (imposed a higher premium for not having LP measures)
- A high ranked company representative has participated in an LP training program
- The maintenance engineer or any other senior engineer has anticipated lightning threats.

A similar survey that has been carried out by the team lead by the author, in 2019, reveals that the situation is not very much changed in South and South East Asia. The latest survey also shows that a risk assessment has been demanded by the LP seeker (from the LP provider) only in the case of the last two reasons listed above. Such cases were a clear minority among the total list of respondents. The awareness of a majority of the respondents on the globally or nationally accepted LP standards, was disappointingly low, despite the majority of the respondents were either engineers or engineering managers. Two relatively small countries, Sri Lanka and Singapore showed marked difference in the knowledge and awareness of their engineers with respect to the LP measures, standards and good practices. A large number of training programs conducted by several expert groups in these countries could be the reason for this exception.

As it has been observed in the surveys done by Gomes and Gomes [4] and also that by the authors' team in the recent past, the lack of correct motivation in the decision making of installing LP system opens an opportunity for the vendor to dictate the selection of LP scheme to the client. The lack of paying any significant attention to the risk assessment by the client gives the advantage to the vendor to decide the level of protection and the number of items, where and what to be installed etc.

Most often it has been noticed that the opportunistic vendors have made unnecessary or sometimes even hazardous selections. In recommending these LP measures, one could clearly notice the ulterior motives of the vendor, which is far from technically and scientifically sound facts and figures.

The most common unscrupulous practice among many LP vendors was to provide a structural protection system to a building that has an extremely low risk of strike as per a proper risk assessment. These buildings include low rise buildings in areas of low lightning occurrence density, totally metallic structures made of suitably thick materials where only a simple earthing system is the only requirement, and buildings protected by high rise structures in the near vicinity (e.g. base stations underneath tall and well-grounded metallic towers). The vast majority of installations in such cases are non-conventional LP systems, predominantly, early streamer emission (ESE) devices. The ESE technology has not been adopted by the International Standards (IEC) or most other national standards due to its lack of scientific grounds or technical justification. As the installations mentioned above are on low or no risk buildings they do not pose any significant probability of strike even without the LP system. Thus, the vendors who provided LP is at almost zero risks of failure. Such cases also contribute immensely to the no-accident statistics of installations with non-conventional devices, which is a false indication of the success of the technology.

Implementing LP systems, especially those consist of copper components on all-metal structures, have another adverse effect. Copper down conductors on buildings made of steel metal structure and corrugated steel roofing strongly promote the corrosion of the steel due to the galvanic effect. In most of the cases, the dimensions of the roofing and supporting materials are well above the minimum values specified in IEC 62305-3 [7] for being self-sufficient air-termination and down conductor system. However, the unnecessary installation of the LP system causes serious corrosion problems which are detrimental to the building structure, especially in areas with high salinity and acidity in rainwater.

Another financially and technically erroneous LP practice that can be noticed in many countries irrespective of the region (as per the informal investigations done in the Middle-East, South and South-East Asia, and Africa), is the installation of an unnecessary number of surge protective devices (SPDs), without a proper coordination plan. It is not uncommon that commercial and industrial sites, where the authorities have requested LP vendors to provide protection to their equipment, SPDs have been installed without any justification with respect to the selection of location and specifications. In these cases, it has frequently been noticed that some robust equipment and components are over-protected whereas some sophisticated equipment and systems are under-protected or not protected at all.

The issue of the suitability and scientific background of the non-conventional air terminations has been debated for almost two decades now. The percentage of LP systems installed according to IEC 62305-3 [7] or similar is less than 5% in Sri Lanka, about 20% in Malaysia and about 10% in Indonesia. The rest are partial protection systems (usually single copper rod grounded by a single down conductor). Pakistan, Bangladesh, Nepal, and the Middle-East is yet infiltrated by the vendors of

non-conventional technology. In Singapore, such technology is forcefully suppressed as a result of the dominance of few individuals.

It is of interest to analyse the human psyche that tempts to adopt technologies that have not been accepted by international and their own national standards and rejected by a clear majority of the scientific community. Irrespective of the fact that the performance of such technologies is unproven, theoretically, experimentally or statistically, it seems that the products based on such technology are successfully marketed in South and South-East Asia, and even in several developed countries in Europe. In some countries, such as Malaysia, despite government warning not to adopt non-conventional LP systems, the visual observations could make a rough estimation that over 75% of lightning structural protection systems installed are non-conventional. The following reasons could be figured out for such an overwhelming number of non-conventional systems.

- Inclusion of the predominant non-conventional LP system, ESE technology has been included in French and Spanish Standards, despite they are not recommended by many other national standards in addition to the IEC Standards. Being well-developed influential European countries, France and Spain make a considerable psychological impact on developing nations. Once said that such countries have included ESE technology in their standards the product gets an automatic endorsement to convince the general public regarding its efficiency. Even under a legal framework, the vendor is safe as his product is in compliance with a European Standard.
- Non-rejection of ESE technology by any standard is another Standard-related issue that could be noted. Although many standards have not included ESE technology in their recommendations, none of the standards has a vehement rejection of the ESE technology. Under such circumstances, there are simply no grounds to persuade an ordinary engineer to reject a product based on ESE technology. One cannot expect a field engineer to read research papers or scientific documents as they are burdened with routinely work. The situation becomes even tougher for an anti-ESE campaigner when it comes to the convincing of decision-makers who are most often non-technical personnel.
- The introduction of ESE and other non-conventional technology as a new technology is another marketing strategy adopted by such vendors. It is very natural that the general public loves modern technology. The ESE proponents use this human thinking pattern much to their advantage.
- The lucrative appearance of many non-conventional air-termination systems compared to simple metal rods is a much attractive object to the human eye and mind. In contrast, ESE air-terminations come with various shapes and chrome plated surfaces. To compete with such advantages acquired by non-conventional LP vendors several manufacturers in some countries promote conventional systems.
- In contrast to an LP system designed according to IEC 62305-3 [7] or similar, an ESE technology-based LP system, designed according to a standard such as NFC-17-102 [12] or UNE 21186 [14] is less laborious and more convenient to

be installed. Especially in the case of buildings that have decorated and complex shaped roofing, non-conventional technologies are much convenient to be installed and also be hidden from the public view (to preserve the aesthetic appearance).

- The marketing promotional campaigns of vendors that sell non-conventional LP systems are much more rigorous and aggressive than those of other companies. The major reason for such affordability for marketing campaigns is the large profit margins that have been enjoyed by the ESE device vendors.
- Another, unchallengeable strategy adopted by non-conventional system vendors is to reward heavily the consultants that recommend and promote such technologies. The large profits gained by the vendors make it permissible for them to offer lavish rewards to the consultants, thus, in turn, they get more business; hence more profits. This positive feedback loop gradually adds more consultants into the loop and destroys the companies that are reluctant to stay away from the loop. During the last five years of this investigation, most of the companies that were previously reluctant to market ESE technology were sucked into the loop as they could not survive in the business outside the loop.
- The non-conventional system manufacturers and marketers have created an atmosphere in many countries that the total solution of LP depends on the efficiency of non-conventional technology. Hence, there are numerous cases where the LP seekers demand non-conventional systems, despite the attempts made by the scientific community to make them aware of the reality. In such cases, the LP assignment consists of both structural and surge protection, thus refusal of providing a non-conventional structural protection system results in the rejection of the total solution by the client. Such a situation prompts even those who are against non-conventional systems to include such systems in their business plan to ensure that they will not lose opportunities to market their surge protective devices.

3 Issues Due to Erroneous Engineering Practices

Similar to any other technical solution in power systems, LP should also be considered as an integral part of the entire electrical network. Thus its success strongly depends on the overall correctness and appropriateness of the engineering practices adopted in the electrical system. Several investigations have reported that in a number of cases the losses and damages are attributed to are wrongly lightning; whereas the real cause is the erroneous electrical installation and maintenance. The LP vendors are also responsible (partly) for such mishaps. As per the surveys conducted by Gomes and Kadir [5] and Gomes and Gomes [4], LP vendors often forward quotations, without getting the service of a consultant, or even visiting the premises to find the actual situation. Thus, the recommendations are solely depending on a line diagram in most cases. Even if a team visits the premises either in advance or during the installation of LP systems, the vendor hardly requests the customer to rectify the drawbacks of the electrical system, when such are noticed. This is done either due to the lack of knowledge on the problem or the fear of losing the contract. The result

will be the failure of equipment even after the installation of the LP scheme. Several of such problems in the electrical system are listed below.

- Grounding at various points of the wiring system: This is one of the commonest problems in the subcontinent. About 20% of the engineers interviewed in the study by Gomes and Gomes [4] have expressed the view that greater the number of leads from the wiring system to the mother earth better the safety. Most of the engineers who had this view are electronic/communication engineers. As we suspect the recommendation of the manufacturers of communication equipment to have separate (or dedicated) ground may have prompted the engineers to have such view. There were also many installations where the SPDs are connected to a grounding system different from the power ground.
- Wiring system defects: There are many malpractices in the installation and maintenance of the wiring system, as we have observed. A few of them are stated below.
  - Selection of wrong colour code: We have come across few sites where even green/yellow grounding wires are used for live or neutral at few locations of the wiring system, which may be extremely hazardous.
  - Damaged wires due to mechanical mishaps and rat/squirrel bites: Ina addition to the safety threat, such damaged points give rise to regular arcing, generating transients in the system. In the Middle-East and some parts of South and South-East Asia, we frequently observe damage to outdoor cable insulation due to extreme weather conditions.
  - Birds/squirrels make nests in panel boxes: Such animals and parts of their nests may cause sporadic arcing between bus bars.
  - Unplanned power feeds routed outdoor: One of the biggest challenges of rectifying the wiring systems is to figure out and remove/re-route power lines that extend to outdoor feeds from points within the building. To make the situation worse, the extensions are most often taken from unsuspecting points; plug points, lamp holders, or even splitting the insulation of the wires at any place convenient to the technician. Typically, these extensions are done on a temporary basis and after the purpose is served the extension is left unattended.
- Absence of electrical safety devices: In the entire sub-continent it is only in Sri Lanka the installation of both earth fault tripping and over current tripping devices are compulsory. In the Middle-East and South East Asia most of the industrial sites are installed with such devices but not in small-scale out-of-city industries.
- Unattended defective electrical appliances: Flickering fluorescent lamps, noise generating old UPSs, defective capacitor banks and inductive loads etc. are few examples of transient generators within premises.
- Irresponsible switching operations: We have come across on several occasions the on–off operations of some sophisticated loads have been done by inappropriate means. One common example is the switching on–off large number of computers by on circuit breaker, to save time and labour.

4 Unethical Marketing Practises

There are two unethical marketing strategies used by a few sectors of the LP service providers, mostly in Asia and Africa. One of them is the testing of their products for a certain quality of their product and interpret the certification from a totally different perspective. A common example is the wrong interpretation of the impulse current withstanding capacity test outlined in IEC 62305-3 [7] for structural protection components, as an endorsement of ESE and other non-conventional technologies. The IEC and several other reputed standards specify a certain lightning current that all protection components should withstand. The test results reflect the ability of the component to withstand up to a certain maximum impulse current once it is injected into the component. This withstanding value depends on the material and dimension of the component and waveform characteristics of the injected current. The test results do not indicate or even imply at all the ability of the component, especially the air-terminations to attract or repel lightning step leaders. However, pathetically, the ESE vendors interpret such test results as the endorsement of their product by the relevant international or national standard in effectively attracting lightning, whereas proponents of lightning repelling systems (another non-conventional technology) interpret the same certification as an endorsement of their product's ability to diverge lightning away from the structure.

Another very problematic issue in many countries (both developed and developing) is the marketing of fake LP devices, especially SPDs. The issue is much serious in developing countries compared to that in developed countries due to the below standard practices of policy implementations and import regulations. There are many electrical items in these countries, especially those related to LP systems, that have been counterfeited by copying popular product brands. In many other electrical products, the counterfeit has some value, although the quality is most often less than that of the genuine item. Hence if the price is proportionately low, people buy them, sometimes knowingly, although such purchase is not ethical in the strict sense. On the contrary, the counterfeit SPDs have zero value (except for the plastic casing and the material filled inside to increase the weight).

In one such case that has been come across during an investigation, Gomes and Kadir [5] report the following observation. The SPDs showed in Fig. 1 bear a reputed international brand name, and are installed in the premises of a financial institute in South Asia. The investigators have noticed that one of the SPDs in the panel is discoloured with smoke/burn signs in the panel and panel cover. The fault indicator of the SPD (the red colour button that should pop out in the event of SPD failure) shows that it is in good condition. The investigation team has requested the technical personnel of the institution to remove the SPD from the panel and dissected it to inspect inside. The team has found a partially melt lump of PVC-like material inside. There were no signs of any surge protective component such as MOVs, GDTs, Zener diodes etc. The fake product designers most often become very successful in their endeavours so that their products look identical in appearance to the genuine component so that even the experts in the technical field could not identify the

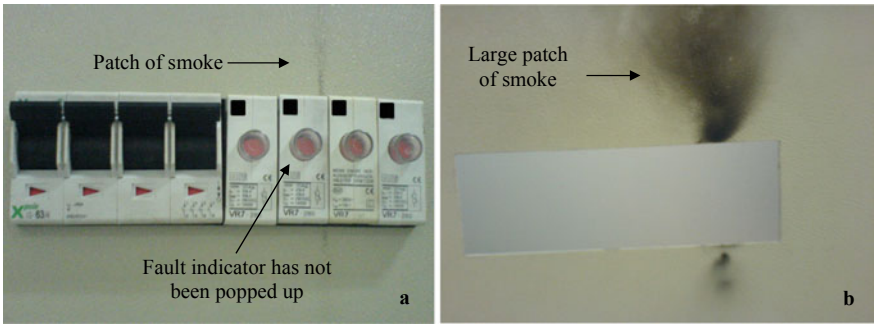

Fig. 1 **a** Damaged SPD with a faked brand name. Note that the fault indicator has not been popped up irrespective of arc signs. The defected SPD has been discoloured showing signs of internal heating, which was verified on opening the device. **b** Cover of the panel with a large patch of black smoke. Adopted from Gomes and Kadir [5]

counterfeit without conducting a proper test. Therefore, it is a tough task to provide public guidance on identifying fake devices with simple observation, in the case of LP items. The national standard institutions and such committees should bring up strict policies and guidelines to monitor the quality of products that are imported to the country and also produced within the country.

5 Engineering and Management Attitudes

The experience of authors in the South and South-East Asia, and Africa reveals that in most cases of electrical system failures, sociological and psychological causes are responsible for the mishaps than the technical causes. These causes play a significant role in the prevention of lightning-related hazards in many industrial and commercial premises. An investigation that was done by Gomes and Gomes [4] show that administrative barriers and rigid attitudes at managerial capacities could hinder the performance of subordinate technical staff in taking the right decision at the right time. A few of these cases are discussed below.

Several field-level technical personal who have been interviewed stated that they are highly reluctant to work beyond their routine workload in rectifying any technical issues unless there are catastrophic cases. In a majority of institutions, the decisions to invest in infrastructure development are taken at the managerial or directorial capacity of which the composition has no technical or scientific background. Hence, to convince such capacity the technical staff needs to quantify the safety and protection in terms of monitory values. Such practise is tedious and the ordinary engineer/technician is hardly rewarded for such efforts. Thus, once lightning-related losses and damages are observed, instead of rectifying ground-level issues (such as wiring defects, power/signal line routing errors, placement errors of equipment, general grounding faults etc.) the engineer or technical in charge tends to make a

recommendation to the management asking for installing an LP system. On this recommendation, the authorities call quotations from LP suppliers. As there are, most often, no knowledgeable personnel in the staff to evaluate the quotations, the contract is given to the lowest bid, unless there are some other non-technical reasons to award it to a higher bid. Sometimes, the management rejects the request to install a surge protection system after installing the structural protection system (or vice versa), stating that an LP system has already been installed.

Gomes and Gomes [4] has also reported that at several institutions the management has asked the engineering staff to refer the request for an LP system to the financial departments to check the possibility of obtaining insurance coverage against the lightning hazards in the place of an LP scheme. Due to the high competition among the insurance companies and also due to the lack of knowledge on LP, most of the insurance companies cover the risk against lightning damage (and even the losses due to downtime) without demanding a proper protection scheme.

In most of the industrial and service sectors, the administers are very reluctant to shut down the power supply for the requirements of rectification or replacement. However, the management overlooks the fact that in the event of transient damage the most probable outcome is the unexpected and uncontrolled power outing, which may cause an extensive downtime loss.

Sometimes the installation of the LP system needs structural or electrical network alteration which is a burden for the maintenance engineers as they need to plan and design modifications and relocations that are outside their routinely work. Apart from this attitudinal barrier from the maintenance sector, some psychological inertia could also be displayed at the administrative or managerial level as such additional infrastructure modification needs various financial and regulatory approvals. Thus, in such situations, taking an insurance policy to cover potential losses becomes most often preferred to the adaptation of comprehensive LP measures.

6 Lightning Protection as a Business Model

Being a relatively focussed field of engineering sciences, LP is treated as a business sector that requires highly specialized technical expertise. Such conceptual norms at the societal level place LP consultancy, design, supply and commissioning, a commercial venture that is operated by a narrow layer of the business community. Since such expertise is not very common even among electrical engineering and technical sectors, only a limited number of private and public institutes could provide the service to the protection seekers. This is one of the prime reasons that in many countries LP is treated as a practice of affordable society. In reality, the research done in many developing countries reveals that lightning-related deaths and injuries are more prevalent in underprivileged communities than that in the affluent society [6, 13]. In this backdrop, it is highly recommended to popularize LP as a business venture among industrially and economically backwords societies in developing countries. Such expansion of business activities will serve two burning issues of many

countries, especially those in landscapes of high lightning density; LP measures will be more affordable to many underprivileged societies that badly need such, and a significant number of employment opportunities will be opened to the job market at the lower-technical end.

LP as a business model yields several expertise and skills at a few levels of education. Thus, if LP is introduced as a viable business at lower-economic layers, one should develop a practical model to address these requirements. On top of the business model, there should be an entity that provides a mechanism for guiding the stakeholders.

- Role of the lightning centre

As it is described in the previous chapter, a lightning centre (LC) in a given region has to play a key role in developing entrepreneurship among suitable candidates. The service required from such LC includes developing financial model, selection and training of entrepreneurs, updating the entrepreneurs with the latest knowledge, and information on various components and materials available at the local level, supporting them in addressing technical issues and providing the trained personal the social recognition in the target communities. The LC is also expected to ensure that the trained entrepreneurs do not fall into prays of the vendors that market fraudulent and unscientific products/technologies.

- Basic training and skills development

The LC may select 5–10 people with medium financial strength and preferably some fundamental technical knowledge and educate them in LP measures. LP education should include, basic concepts of lightning, human safety, risk assessment, structural protection, surge protection, installation concerns, costing and budgeting and engineering, technical and business ethics. As it was discussed in the previous chapter, this knowledge should come from the international/national level to the LC level. The selected entrepreneur should be a trainer for his employees thus, the LC needs to conduct regular programs of training of trainers. Once the candidate successfully completes the training program, the LC could issue a certificate and an identification card to the entrepreneur recognizing his skills and abilities. Such recognition is essential for a fresh technical entrepreneur to build up the confidence and trust of society. The LC can also publish a list of authorised technical personal (by the LC) on their website so that protection seekers can check for the validity of the entrepreneur's claims.

- Financial model

One of the toughest hurdles for a low or medium-income entrepreneur in developing countries is to find the capital and initial operating investment. A majority of financing institutes such as banks are reluctant to provide loans for such individuals due to the lack of confidence. The LC can be the mediator in such a case as they get a better impression of the ability of the entrepreneurs by the end of the training program. There is also a possibility that the LC itself could be able to win funding from various institutions (both governmental and non-governmental) to support the entrepreneurs.

In such cases, the LC may develop their own business-monitoring mechanism to make sure that the ventures move in the right direction.

- Risk assessment and design

The biggest challenge in venturing into LP as a viable business is the requirement of conducting risk assessment and consequent design of the LP system for a complex installation, according to the outcomes of the risk assessment.

In the modern world, computer literacy is fast improving among even the lower economic layers of many developing countries. Therefore, it may not be difficult for the business owner (henceforth termed as the entrepreneur) to get the service of a person to use risk assessment and design software to produce the required LP layout. As such computation and simulations need occasionally, the entrepreneur may come to an agreement with the IT specialist for getting his service on a hire-on-demand basis.

The available software of risk assessment and LP measure design in the market are relatively expensive and the usage of such software by one entrepreneur is occasional. Hence, it is greatly advantageous if the LC purchases the software and hire it at an affordable fee to the entrepreneur. In this case, based on the demand, the LC may hire an IT expert or train its own staff member to run the computation.

- The responsibility of the company (entrepreneur)

The LC has the prime responsibility of educating the entrepreneurs on engineering and business ethics as an essential part of the training program. In contrast to marketing consumables or other luxuries, LP is a business that involves the safety of human life. Thus, the businessperson should have deep knowledge on his/her responsibilities and commitments to the protection seeker and the society as a whole. The lack of knowledge on a particular technology is not a justification for failures or lapses in the products/services provided. Both the LC and the companies are urged to look for scientifically accepted low-cost solutions that can be given to the shelters of underprivileged societies, who could not afford standard LP measures even at a significantly reduced cost. The international research frontiers are regularly updated at present with information of the availability of such measures.

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