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Applications of DAETE Model

Implementation of Digital Twin

Highlights

Radio Optics of Metamaterials

Quality of Continuing Engineering

Discovering Thoughts, Inventing Future

VOLUME 21 ISSUE 3 VERSION 1.0

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Analysis of Changes in the Procurement Process in a Transport Company Caused by Implementation of Digital Twin

By Yekaterina Kovaleva
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Abstract- This article illustrates the changes in the process of purchasing parts and components in a railway company when implementing a smart asset management system. The processes built in BPMN notation illustrate the flow of work that is understandable for people with different backgrounds. When analyzing the process as it is, the company's weaknesses were identified, which justified the need to introduce new technologies. In the modern world, there are many solutions for asset management automation. During the analysis, it was decided that the company needs a new information system supported by the constant collection of data from smart sensors. Such a system is a digital twin of vehicles, which makes it possible to predict future changes and make timely decisions. To demonstrate the improvements that the company can get, the processes were built as they should be, and conclusions were drawn on what positive effect the implementation of the new system will have.

Keywords: *digital twin, IoT, business processes automation.*

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ANALYSISOFCHANGESINTHEPROCUREMENTPROCESSINATRANSPORTCOMPANYCAUSEDBYIMPLEMENTATIONOFDIGITALTWIN

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Keywords: digital twin, IoT, business processes automation.

I. Introduction

The transition to digital technologies has been the main task of companies ' development for several decades. Even such conservative areas as rail freight are trying to keep up with the times and introduce technologies such as the digital twin. The object of the study is exactly such a large company that transports oil across Russia and border countries. The digital twin allows a company to create a digital copy of its assets containing all the necessary information to help make a decision[1].

However, despite the general awareness of the importance of digitalization, companies often find it difficult to understand the potential impact and benefits of digitalization. For successful implementation of the technology, it is necessary to analyze the potential impact of digitalization, a company must first analyze existing trends and their relevance to the company. Next, determine which drivers caused the desire for digitalization, what scenarios of changes are possible, and what goals the company pursues. Then to study the current state of the company and determine the gap between this state and the desired result, choose an approach that can cover this difference and then act [2].

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For a qualitative assessment of the company's existing activities to avoid failure in the transition to new technologies, business process analysis is widely practiced in the world. Building diagrams that are understandable for businesses and developers helps reduce misunderstandings between the two groups, as well as identify bottlenecks in the company's activities [3].

That is why the subject of the work is the analysis of changes in the process of unplanned purchase of parts and components when implementing a digital twin in a transport company.

It is important to note that the automation of procurement is currently an actual direction, as this process improves not only the company's performance indicators, but also develops the circular economy, that is, increases sustainability [4].

This paper presents analysis of the company's activities through modelling the procurement process as it isand assesses the weaknesses of the existing model. Further, the analysis of technologies that can compensate for the existing shortcomings is carried out. After that, a model of the process is built, how it should be, and the positive effects of automation are highlighted. After that, conclusions on the work are made

II. Methods

For this research it is important to consider the context, namely the specifics of the company in which the IoT implementation takes place. The idea of this paper is to understand the changes of processes that appear because of technology. Thus, a case study is used as a research method. A case study studies contemporary phenomena in their natural context, including people and their interaction with technology. As part of the research, the business processes are analyzed to understand how future system should affect the company's performance [5].

a) *Analysis of the performance of the company*

The company under discussion is a rail freight carrier. It operates on the territory of the former Soviet Union and transports oil and oil products. The main processes of the company are shown in Figure 1.

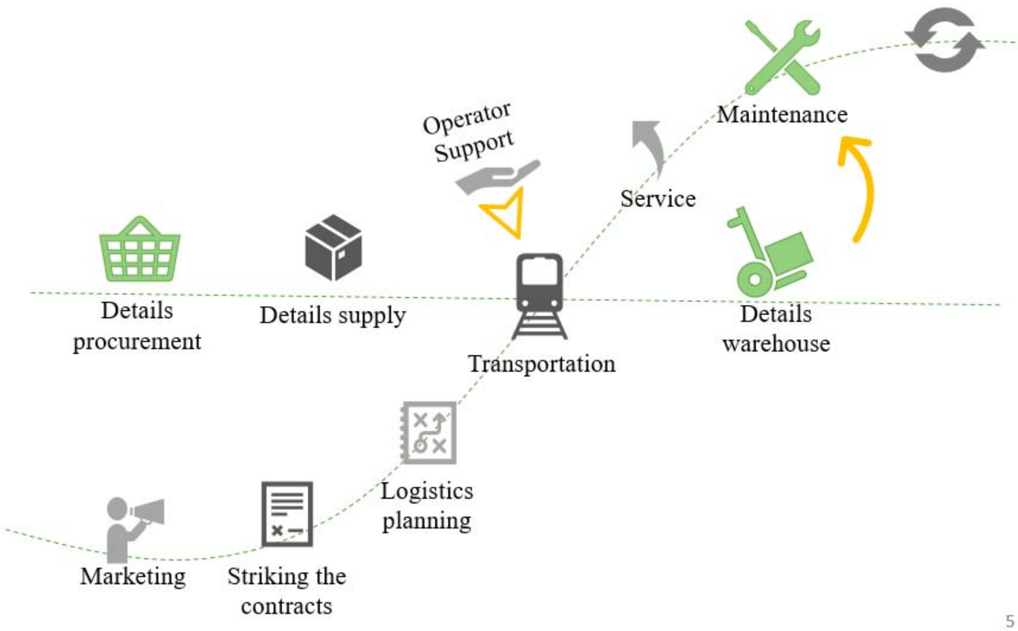

Figure 1: Company's performance

An important aspect of the transport company's activity is the repair of vehicles. Every day the depot receives cars and locomotives with malfunctions. Emergency stops lead to temporary and financial losses. Thus, the company decided to focus on the automation of this activity. The main processes in this area are maintenance, purchasing of parts and details and their warehousing. This article examines the impact of IoT implementation on the purchase of parts.

One of the tools for analyzing the company's activities is business process modeling. It allows to build a bridge between the views of the business and the vision of software developers. Models allow to look at the weaknesses in the company's activities and find solutions to overcome them [6].

One of the most understandable notations for business representatives is BPMN. The main objects in this notation are tasks, events, and gateways, which are flowchart hosted by actors executing the process [7].

To understand the impact of IoT on the purchase of parts and components, the process of purchasing unplanned parts was described and presented in Figure 2.

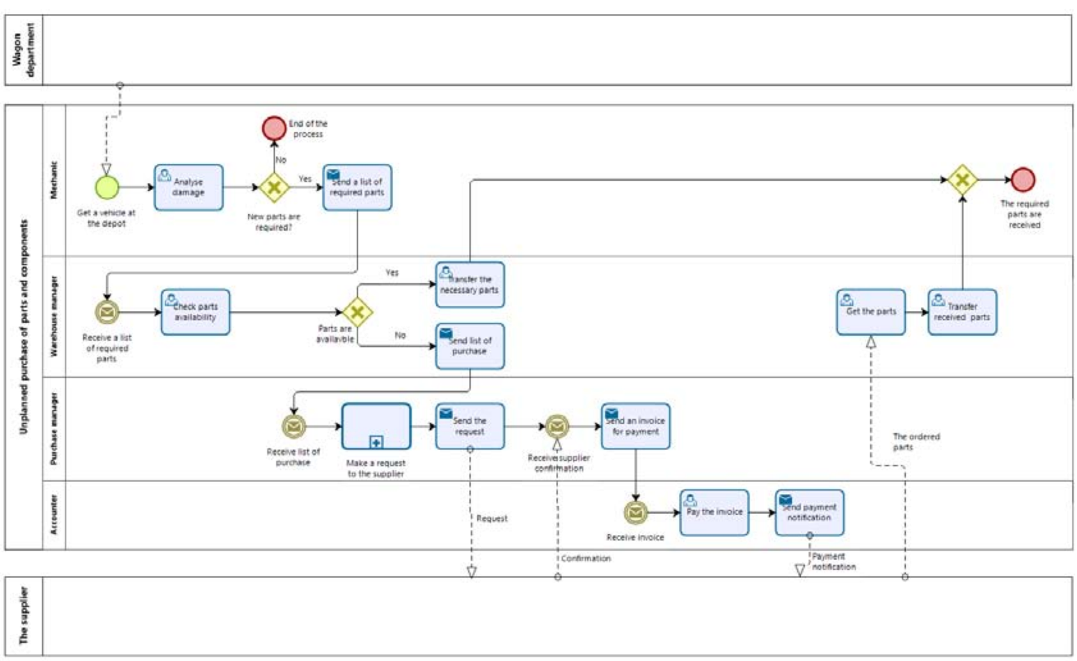

Figure 2: Unplanned purchase of parts and components "As is"

From this diagram, the broken vehicle is sent to the depot, where the mechanic determines the scale of the breakdown. Based on the results of the analysis, a list of necessary parts is compiled, which is sent to the warehouse manager. The availability of parts in the warehouse is checked and, if they are not available, a list of purchases is compiled. Next, the purchasing manager sends a request to the supplier, after which the accountant pays the invoice. After some time, the parts get to the warehouse and are transferred to the mechanic for repair. It is worth noting that to simplify the process, it has been accepted that the purchasing manager always receives confirmation from the supplier, since this does not affect the analysis of the process in this context.

For a more detailed analysis, consider the subprocess of creating a request to the supplier shown in Figure 3.

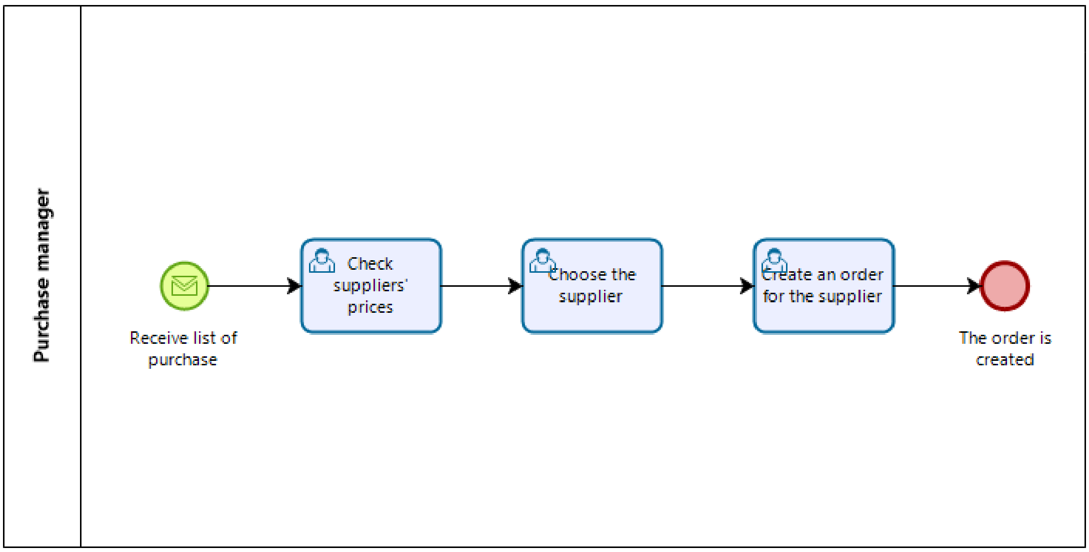

Figure 3: Make a request to the supplier "As is"

In this diagram, you can see that the purchasing manager checks the prices of suppliers, selects the appropriate one, and creates a request.

The first disadvantage of this model is that the damaged vehicle must be pre-diagnosed, which extends the time of repair.

Secondly, now the company does not have a specialized software product that provides inventory control in the warehouse. All information about parts and components is entered into the MS Excel program, which is why the process of checking the availability of parts in warehouse takes a long time.

Third, when analyzing the company's activities, it was revealed that there are no regular scheduled inspections of the quantity and quality of parts available in warehouse. In this regard, there is a frequent purchase of duplicate parts, which carries extra costs in the company. It is important to note that the company has several distributed warehouses, but there is no joint database of stored parts in different warehouses, which also makes it possible to purchase duplicate parts.

Finally, the company does not consider the quality of parts of specific suppliers, which leads to the continuation of the purchase of low-quality parts.

Summarizing the above conclusions, it could be said that that the company's processes are imperfect and lead to time and financial costs for long processing of requests, as well as possible purchase of low-quality and duplicate parts.

b) Description of technology

The processes of maintenance, part procurement and storage are closely linked and integrated under assets management. The main document regulating this activity is ISO 55000, which contains recommendations for managing the company's assets [8].

To automate this process, the market has long used Enterprise Asset Management systems that allow to implement the recommendations proposed by the standard. These systems provide automated operation of many processes, including the purchase of parts and components [9].

As well-know, now the world is in industry 4.0, the satellites of which are blockchain, big data and the Internet of Things [10]. Together, these technologies create an environment for creating a digital twin that allows you to take asset management to the next level. The digital double is a simulation of a real object, built based on data collected through sensors within the cyber-physical system (CPS) [11]. CPS is several sensors that monitor the condition, in this case, of parts and components of vehicles and transmit data via a wireless network. This data is then analyzed to help in decision-making process [12].

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Such a system is built on the following stages: data collection, data processing, detection, diagnosis, prediction and decision-making. Data collection is carried out by a variety of sensors that transmit data wirelessly. Then, the collected raw data is cleaned up to perform analysis. Breakdowns are associated with many causes, so it is important that the system notices these triggers. Further, diagnostics are carried out, based on which forecasts are made and decisions are made on the replacement or repair of vehicles[13].

The digital twin allows to constantly monitor the state of assets and based on this, predict the future state of certain vehicles. Such analysis can significantly improve the procurement process, optimize the storage of parts in warehouses, and track the quality of purchased parts [14].

Thus, to ensure high efficiency of the process under consideration, the company needs to implement an asset management system supported by technologies such as IoT, data analysis, which allow to build a digital twin.

III. Results

The introduction of an asset management system with Internet of Things technologies will lead to significant changes in the company's activities. First, this will affect the control of the technical condition of vehicles and will reduce the number of unexpected stops, as well as reduce the need for routine inspections [15].

Constant monitoring of the condition of parts will also reduce planned purchases, buying the necessary parts as they wear out. This will free up space in the warehouse and possibly reduce storage space. Also, the chance of parts falling into disrepair during storage is reduced, as parts are purchased as needed. The changes that will be made to the process of unplanned purchase of parts are shown in Figure 4. This diagram shows the process as it should be.

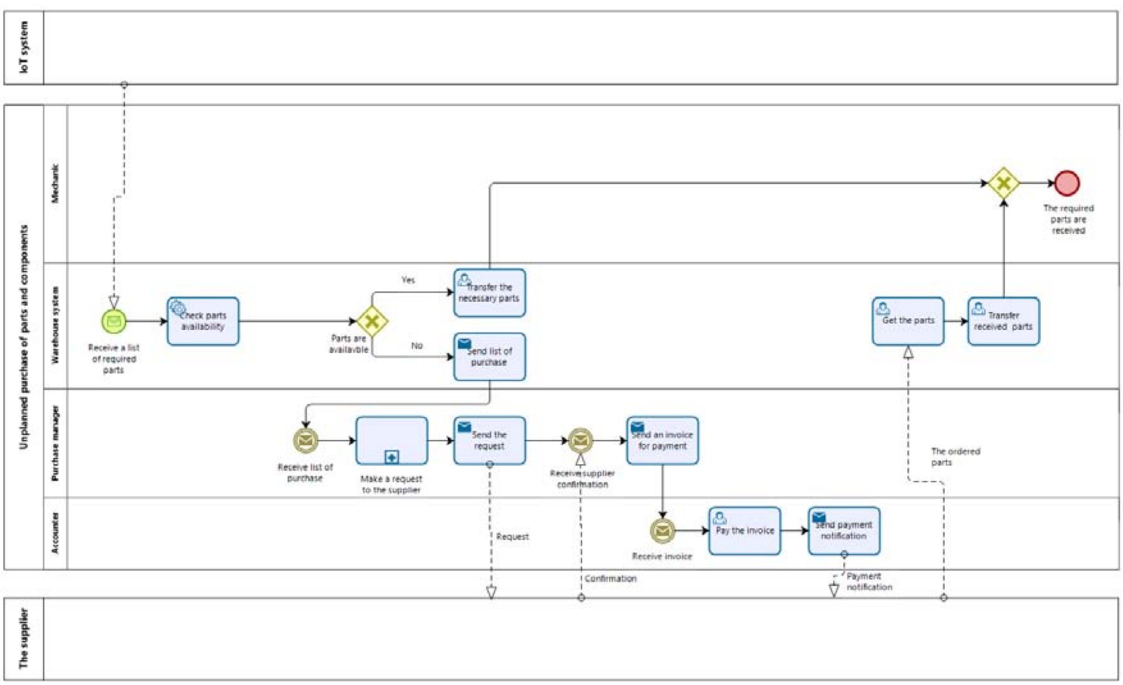

Figure 4: Unplanned purchase of parts and components "To be"

As could be seen in the diagram, data on broken parts are sent directly to the warehouse system, where they are checked for their presence. If they are not available, the list is sent to the purchase manager. In this case, the changes can be seen in the decomposition of the process of making a request to suppliers, shown in Figure 5.

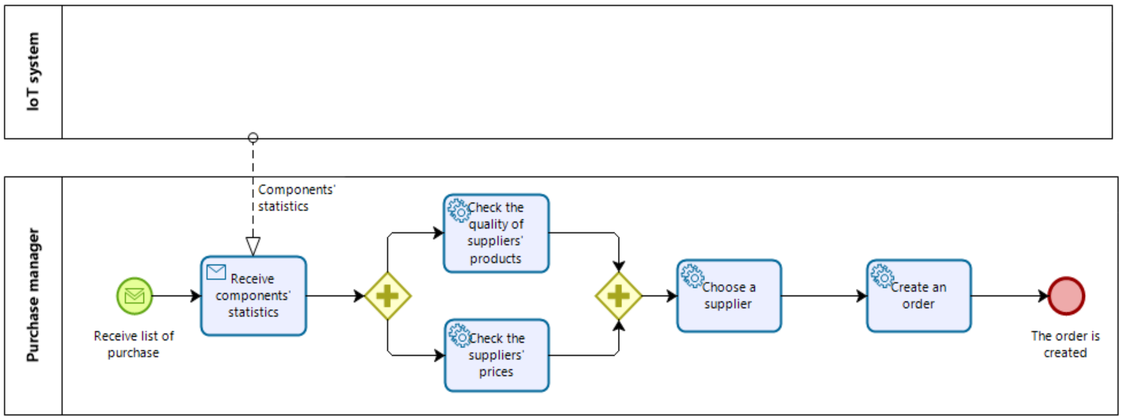

Figure 5: Make a request to supplier "To be"

Based on the data collected by the sensors, the company can monitor the quality of parts, thus checking whether the supplied parts meet the requirements. Otherwise, the company may terminate contracts with unscrupulous suppliers. Moreover, the new information system will allow to automate tasks.

Such changes will lead to a significant reduction in the time of stops. Additionally, a timely response to deterioration, implemented by the digital twin, will reduce the number of emergency repairs to a minimum.

IV. Discussion

This paper examines the impact of the introduction of digital technologies on the procurement of a transport company. The creation of a digital twin introduces changes in various aspects of the business and the change in the procurement process is directly related to these changes.

The paper considers the workflow as it is and reveals that the process of emergency repairs, including unplanned purchase of parts, takes a long time. Such long stops lead to financial losses, as the company receives fines for delayed delivery.

As a result of the analysis of weak points in the activity, it was determined that the company needs an automated asset management system, whose data is backed up by a cyber-physical system that creates a digital twin of vehicles.

Under the constant monitoring of sensors, the process of checking the technical condition of objects is first reviewed. This makes it possible to predict breakdowns and restructure the processes of planned repairs, and what is important for this work, purchases. Sensors allow to predict a malfunction, which means that the company can purchase the necessary parts in advance. In this case, in case of failure, the parts necessary for repair will already be in warehouse. Moreover, the number of emergency stops will decrease, as managers will know about the impending failure in advance and act before they occur.

The process improvements are visible in the diagram as it should be, the diagram helps to understand what the company is striving for and serve as an instruction for the developers of the future system.

V. Conclusions

In this paper, the analysis of changes in the processes of unplanned purchase of parts and components was carried out.

In the built model, the long process life was noted, as well as low automation, which leads to poor quality accounting of available parts in the warehouse, the lack of quality control of products from various suppliers. By using modern technologies, such as the Internet of Things and Big data analysis, the company can build a digital twin of its vehicles, thereby enhancing the capabilities of its activities.

Based on the diagram as it should be, you can see that technologies allow you to speed up the process, automate tasks that were previously performed manually, and analyze statistics to select bona fide suppliers.

References Références Referencias

1. Benjamin Schleich, Nabil ANWER, Luc Mathieu, and Sandro Wartzack. 2017. Shaping the digital twin for design and production engineering. CIRP Annals - Manufacturing Technology 66, 1 (2017). DOI: https://doi.org/10.1016/j.cirp.2017.04.040
2. Adriana Neligan. 2018. Digitalisation as Enabler Towards a Sustainable Circular Economy in Germany. (2018), 7.
3. Jörg Becker, Michael Rosemann, and Christoph von Uthmann. 2000. Guidelines of Business Process Modeling. In Business Process Management, Wil van der Aalst, Jörg Desel and Andreas Oberweis (eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 30–49.
4. Procurement 4.0 and its implications on business process performance in a circular economy |

Elsevier Enhanced Reader. DOI: https://doi.org/10.1016/j.resconrec.2019.104502
5. Creswell J. W, 2003, Research Design: Qualitative, Quantitative, and Mixed Methods Approaches – case study
6. Marlon Dumas, Wil M. van der Aalst, and Arthur H. ter Hofstede. 2005. Process-Aware Information Systems: Bridging People and Software Through Process Technology. John Wiley & Sons.
7. Birgit Korherr and Beate List. 2007. Extending the EPC and the BPMN with business process goals and performsnce measures. In Proceedings of the Ninth International Conference on Enterprise Information Systems, SciTePress - Science and and Technology Publications, Funchal, Madeira, Portugal, 287–294. DOI: https://doi.org/10.5220/0002379002870294
8. IbifuroIhemegbulem and David Baglee. ASSESSING THE EFFECTIVENESS OF ISO 55000 STANDARD IN SMALL TO MEDIUM SIZED ENTERPRISES (SMES). 8.
9. Terrence O’Hanlon. 2005. Computerized Maintenance Management and Enterprise Asset Management Best Practices. (2005), 11.
10. L. Barreto, A. Amaral, and T. Pereira. 2017. Industry 4.0 implications in logistics: an overview. Procedia Manufacturing 13, (2017), 1245–1252. DOI: https://doi.org/10.1016/j.promfg.2017.09.045 DOI: https://doi.org/10.1007/3-540-45594-9_3
11. Elisa Negri, Luca Fumagalli, and Marco Macchi. 2017. A Review of the Roles of Digital Twin in CPS-based Production Systems. Procedia Manufacturing 11, (2017), 939–948. DOI: https://doi.org/10.1016/j.promfg.2017.07.198
12. Jay Lee, Hossein DavariArdakani, Shanhu Yang, and Behrad Bagheri. 2015. Industrial Big Data Analytics and Cyber-physical Systems for Future Maintenance & Service Innovation. Procedia CIRP 38, (2015), 3–7. DOI: https://doi.org/10.1016/j.procir.2015.08.026
13. AtamuradovVepa. Prognostics and health management for maintenance practitioners - Review, implementation and tools evaluation. 32.
14. Marco Macchi, Irene Roda, Elisa Negri, and Luca Fumagalli. 2018. Exploring the role of Digital Twin for Asset Lifecycle Management. IFAC-PapersOnLine 51, 11 (2018), 790–795. DOI:https://doi.org/10.1016/j.ifacol.2018.08.415
15. Oksana Ilyashenko, Yekaterina Kovaleva, DmitriiBurnatcev, and Sergey Svetunkov. 2020. Automation of business processes of the logistics company in the implementation of the IoT. IOP Conf. Ser.: Mater. Sci. Eng. 940, (October 2020), 012006. DOI:https://doi.org/10.1088/1757-899X/940/1/012006

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Case Studies and Applications of DAETE Model to Continuing Engineering Education

By Alfredo Soeiro
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Abstract- The need to choose appropriate methods to ensure quality of continuing engineering education has been an issue of research and of practice for years. Several initiatives were undertaken in the last decades to define the methods of proper assurance of provision and delivery of continuing engineering education. The quality models for education and training have a large variety of approaches that have been applied to all different levels from primary schools to adult learning. Methods employed had no significant success with continuing engineering education due to the particular nature of the training. A proposal for a project was elaborated between universities in Europe and in the USA to develop accreditation procedures to ensure quality of continuing engineering education (CEE) centres. The project (DAETE) applied an adaptation of the EFQM (European Foundation Quality Management) descriptors to the specific contexts of CEE centres. The DAETE model had also been applied in other contexts like accreditation and classification of CEE centers and for training managers of CEE centers staff. The paper also describes these applications of the model in different contexts with emphasis on useful conclusions. Recommendations for the adoption of the EFQM model to organizations involved in education and trainingare made with the consequent adaptations.

Keywords: *continuing engineering education, DAETE, EFQM, recognition.*

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CASESTUDIESANDAPPLICATIONSOFDAETEMODELTOCONTINUINGENGINEERINGEDUCATION

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Keywords: continuing engineering education, quality assurance, DAETE, EFQM, recognition.

I. Introduction to Project

The goal of the project DAETE (Development of Accreditation in Education and Training in Engineering) was to obtain tools and methods that would ensure quality of the CEE (Continuing Engineering Education) centres. Since the project was publicly financed the final outputs are open for use by interested stakeholders like universities, accreditation agencies, CEE centres, human resources departments from companies and adult training organizations (DAETE 2020).

The common methods for ensuring quality in education and training have been educational bench marking, implementation of diverse ISO norms, adoption of standards of practice, using specifications, external auditing, centres output valuation and management following PDCA (Plan, Do, Check, Act) approach. The choice of the method occurred during the first project meeting (AALTO, 2020). Meeting was fundamental to choose the project methodology, the action plan and the task distribution. Choice made by the consortium was the model of EFQM (European Foundation for Quality Management) that was flexible enough to allow the possible acceptance by CEE centres in Europe and in the USA (EFQM 2020).

To mould EFQM to the CEE centres activities the partnership decided to start debating partners´ experiences and practices in terms of quality control and accreditation for continuing engineering education and vocational training. Partnership then planned to analyse and to debate the models that can be used taking account the different experiences on both sides of the Atlantic, to produce guidelines advisable for quality assurance and accreditation, to test the recommendations and to adapt the guidelines to the feedback results.

In fact, CEE centres have, generally, a structure and operational contexts that are different from those existing in their own universities or higher education institutions. Some have large degrees of autonomy, others operate as private foundations or organizations and others are departments or units. CEE centres therefore need proper quality management tools and methods to allow diversity of structure and of operations. The consortium decided also that the project would focus on quality assurance of CEE centres and would not address the individual CEE courses quality.

II. Linking Continuing Engineering Education and Quality

Exchanging theory and practices among the consortium members allowed in the first place a reciprocal understanding of the benefits of the methods and tools used. The diversity of the set of approaches added value in two fields. The first one is that environments that framed the developments of CEE quality have been different among the partnership. In Europe, the research and development about quality evaluation of CEE have been based on projects supported by public funding. In the USA, the quality assessment relies on market analysis indexes and financial indicators. The second is that in Europe the processes and procedures are preponderant to define quality of CEE while in the USA quality relies mostly on results.

EFQM was considered by the partnership as a good combination of processes and of results. This

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combination became a compromise between the management interests of the two groups of the consortium. The model became a practical tool to support CEE centres to achieve high levels of quality by benchmarking results and processes in order to achieve excellence. EFQM model is based on nine criteria. The criteria include five chapters on processes and four chapters on results. The first five criteria addresses what each CEE centre does and the other four criteria analyse results of each CEE centre.

The consortium realized and accepted that leadership and strategy success are achieved through proper combinations of people and of resources. Therefore, EFQM model criteria determine level of satisfaction of CEE centre users, fulfilment of people working in the centre and the impact on the centre in society. The EFQM model proposes self-assessment as a method of complete, systematic and regular analysis of the CEE centre activities and proposes that these results be compared with results of similar organizations.

EFQM model divides organizational processes into nine criteria, each with a certain number of sub-criteria. In the evaluation of the CEE centres the DAETE project created several sub-criteria in each of the criterion. It was necessary to adapt the sub-criteria to the processes and procedures to the needs of the CEE centres. The objective is that processes of a CEE centre maybe evaluated, developed and improved in the different functional areas. Regular monitoring, internally and externally, of these processes may improve the quality and effectiveness of each functional area. Evaluation of relevant results may be used to determine success against values of reference and allow management space to implement improvements.

DAETE model employed the same structure of chapters as EFQM model. It had however to adapt the sub-criterion to the context of CEE. This was done using a thorough debate leading to a set of thirty-six sub-descriptors divided by the nine chapters. A definition of the nine chapters was made and is presented later in the text. The sub-criterion indicators also needed to have a definition of level to comply with the requirement of EFQM model of having levels evaluated-The five levels reflect the development state for the each of the sub-criterion evaluated.

The evaluation of each sub-criterion for each CEE centre consisted in choosing of the five levels of proficiency. These levels of proficiency were chosen portray the state of development and to allow comparison among CEE centres. These levels are (DAETE 2020):

1. Quality depends exclusively on the individual (there is no process); Activities depend on individual initiatives and activities are not programmed globally.
2. Quality is based on basic processes; Responsibility for each activity is no longer individual and there is a tendency to share responsibilities across the CEE centre, with some short-term planning; There is some degree of process definition, however there is no documentation; Performance is assessed occasionally.
3. There is vision through processes and some quality assurance (intermediate processes); There are established standards, procedures and guidelines known throughout the CEE centre; Activities are carried out in accordance with these procedures; Activities are planned with medium-term objectives and indicators are defined for evaluation.
4. There is systematic evaluation and process improvement (sophisticated processes); The established procedures are systematically evaluated to create possible improvements; There is a clearly visible orientation for the CEE centre's user; The activities are planned with well-defined objectives, in the medium and long term.
5. There is the objective of having recognized external excellence (processes of excellence); There is an exchange of knowledge and experience throughout the organization, within the organization and with entities outside the organization (including competitors). The formulation and improvement of the CEE centre's procedures are in accordance with internal and external standards; The experiences and best practices are shared with other entities; There are partnerships and exchanges of information with users, trainers and other centres, etc.

After choosing the sub-criterion the partnership discussed the relative importance of each one. Each sub-criterion had a percentage of the points available for each criterion. The partnership adapted the CEE centres nine criteria of DAETE model as:

Leadership: CEE centres leaders develop and facilitate the fulfilment of the mission and vision of the continuing education centre. They develop organizational values and systems necessary for sustainable success and implement these through actions and behaviours. During periods of change, they maintain a constancy of purpose but whenever necessary, leaders are able to change the direction of the organization and inspire other members of the organization.

Policy and strategy: CEE centres implement the mission and vision, developing a strategy focused on stakeholders and that takes into account the external needs and those of the sector in which it operates. Policies, plans, objectives and processes are developed.

People: CEE centres manage, develop and unleash the potential of the organization's people at the individual level, based on teamwork and the organization. They promote equity and equality, involve and empower people in the organization. CEE centres reward and recognize the people to motivate them to use the skills and knowledge to the benefit of the organization.

Partnerships and resources: CEE centres intend to manage external partnerships and with internal resources to support the policy and strategy in order to have an efficient functioning of the processes. During planning the management of resources and partnerships are done to balance the current and future needs of the organization.

Processes: CEE centres design, manage and improve processes in order to fully satisfy and generate more and more value for users and other interested parties.

User results: CEE centres thoroughly measure learning results in order to have good results.

Results of people in the organization: CEE centres thoroughly measure employee results.

Results related to society: CEE centres thoroughly measure the results that concern society.

Performance results: Excellent organizations thoroughly measure the key results of the policy and strategy adopted.

III. Application of DAETE in CEE Centres

The DAETE table makes part of the DAETE model and comprises the numerical information for each criterion and sub-criterion levels. The table allowed the CEE centres to register the self-evaluation values in terms of each sub-criterion. Since each sub-criterion had a fixed amount of points the levels multiplied by the points it was possible to have a number (between 0 and 1000 points) that reflected the performance of each CEE centre (DAETE 2020).

The table can be used as a self-diagnostic tool for each centre. The results can be applied to define areas in the centre for improvement. Any staff member of the CEE centre can fill the table. This table is generally filled by leaders of centre, institution, unit or department. When using the table it should be considered that there are different types of CEE centres with a wide variety of characteristics such as diversity of work areas, size, organization, financing, legal status, private or public, non-profit, commercial, etc.. Benchmarking with other centres needs to consider this type of differences that may constitute a bias.

Examples of questions that arise when filling the table are: "Why we feel that the level of activity is at this level? How do we interpret the context of the criteria or what are the evidences?" Some criteria are not relevant to certain groups of the staff and, therefore, it is advisable that scores are calculated as averages from various groups. Examples of results among three university centres concerning the nine chapters reflect the differences among centres.

The difference of levels between universities is expressed in terms of chapter Leadership. University A had a total of 68 points and university B a total of 56 points. This chapter comprised the sub-criterion Development of vision and mission, Continuous improvement of management systems, Leadership and external relations and Leadership and motivation. The levels for university A for these sub-criterion were, respectively for each sub-criterion, 3, 3, 3, 4. For university B the results were, respectively for each sub-criterion, 3, 3, 4, 2. The differences of levels can express that university A has good examples and processes in terms Leadership and motivation while university B needs corrective actions to improve. University B showed also that sub-criterion Leadership and external relations is close to excellence (level 5) and may present procedures and processes that can help others improve their own.

It is relevant to notice that among the several answers obtained from the validation and testing of the centres has shown some patterns of results and of evaluations from the self-assessments. The first remark consists that no CEE centre attributed the level 1 to any of the sub-criterion. Since these self-assessments were not audited it is probable that this situation may happen and those making the self-assessment did not want to assume that. Another remark was that high ranking level respondents had the tendency to present high levels while lower level managers or staff had more modest evaluations. There was also noted that respondents from different areas in each CEE centre had different values for the same sub-criterion. That showed that the awareness of the development for each sub-criterion varies in accordance with the function performed by each respondent.

DAETE model proposed a path to excellence of CEE centres based on continuous improvement, self-assessment, good management practices and a planning discipline. The following steps towards excellence were proposed to the CEE centres [DAETE 2020]:

1. Assess where the CEE centre is now: One way to do this is to self-assess the CEE centre. The self-assessment process can help the centre to understand the current status in terms of quality.
2. Define the priorities of the activities of the centre: To align the activities and CEE centre strategy, it is necessary to understand the existing trends and areas for improvement. The fundamental concepts of excellence can be used to compare the centre strategy.
3. Identify what needs to be improved: Self-assessment can help provide a detailed map for

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people in the CEE centre. It can help to answer: "Where do we need to improve?"

4. Identify how to improve: CEE centre staff and management can learn from other centres through comparison ("benchmarking"). It can help to identify good practices from other centres.

To validate and improve the DAETE model it was presented in several conferences, workshops and seminars to test, to disseminate and to explain goals, processes and benefits. For instance, just in 2010 there were several events: ASEE CIEC – Palm Springs, CA, USA; Building Quality in Online Programs Workshop – Madison, WI, USA; UCEA Annual Conference – San Francisco, CA, USA; EUCEN Conference – Rovaniemi, Finland; IACEE-CACEE Meeting – Beijing, China; LACCEI Conference – Arequipa, Peru; ASEE Annual Conference – Louisville, KY, USA; RECLA – Dominican Republic; IACEE 12th WCCEE – Singapore and AMECYD – Guadalajara, Mexico (October 2010).

As a result of this effort of dissemination, tuning and validation about 120 CEE centres, either academic or business oriented, experimented, criticised and validated the DAETE model. Results were of quantitative and of qualitative nature. During the collective sessions the results from each CEE centre were presented and discussed. This allowed a numerical benchmarking between centres.

Qualitative feedback was obtained through a description of the CEE centre that provided information about the dimension, type of operations, management structure, budgets, number of participants, etc. Another feedback was denominated as good examples. Good examples were defined by those related with sub-criterion with level 4 or 5 and were collected to allow other CEE centres to have access to good practices, to understand the procedures that led to the high score and learn from other centres activities.

IV. Other Applications of DAETE

Examples of the application of the DAETE approach comprehend several applications. One example is the adoption of a professional engineering association to externally accredit CEE centres that pay for each accreditation. Another example is the use of a derived model of the DAETE table by a CEE world organization as a consulting service to members. The third example is the use by CACEE (China Association of Continuing Engineering Education) to train CEE managers from CEE centres to improve the quality of results and of training (CACEE 2020).

The first application allows the Portuguese engineering professional association to evaluate providers of continuing engineering education and is based on the DAETE model. It is called ACCEDE and is composed by two phases. First phase is dedicated to a self-assessment by the provider using the DAETE model. Results are subsequently provided to the engineering association. The second phase is composed by an audit of the CEE centre by an auditor nominated by the association. The engineering association has a set of auditors that were previously trained on using the DAETE model. Accreditation of the CEE centre is made based on the numerical result of the final DAETE table assessment. Below a certain number the centre is not accredited. A list of accredited CEE centres is available at the engineering association website. The audit report also includes a list of recommendations to improve the CEE centre (OE 2020).

Second application of DAETE model is called CPD-BQIP (Continuing Professional Development Benchmarking and Quality Improvement Program). It is available for institutional IACEE members that are interested in organizational quality improvement and benchmarking program. It has a database of results from the use of DAETE model facilitating improvement of the quality of the benchmarking data. Intended as part of the forefront in continuing professional development CPD-BQIP is considered as the first ever international standard for managing quality in CEE centres and programs at the organizational level. It is planned to assess quality of CEE centres with respect to standards, benchmark quality against peer institutions and share best practices among similar organizations, to allow continuous quality improvement (QP 2020).

The third application is relevant since CACEE deals with CEE of about 68 million professional and technical personnel nationwide. Staff from CEE centres are trained during a week on how to improve the quality of the management of respective organizations. The training is made each time on a dedicated training centre for about fifty managerial staff. Three days are dedicated to the DAETE model adopted to the country conditions. These days comprise the theoretical background of the EFQM, the description of the DAETE model, significance of descriptors, application of the model to respective CEE centre, presentation of results, debate about adaptation of sub-criterion, conclusions and remarks. It is relevant to notice the possible impact of the DAETE model in the quality of CEE in such a big country.

V. Conclusions and Recommendations

Main conclusion is that DAETE model, based on EFQM, is available to improve quality of management of CEE centres. That improvement will have consequences at the level of engineering activities due to a better qualification of engineers. The validation phase and the diverse utilizations provided evidence of robustness, flexibility and effectiveness of the tool. It is possible that the DAETE model may be adapted to apply in other type of education and training organizations dealing with other knowledge areas and levels of qualification. This is particularly relevant for the sector of education and training where quality evaluations are based mostly on processes and less on results/outputs.

The DAETE model is an appropriate combination of quality assessment mixing procedures and results/outputs indicators. Of course, the referred examples illustrate different uses of the DAETE model and also show the relevance and impact of the approach. Many CEE centres have also expressed the appreciation of having a tool that allows a self-evaluation tool that fosters reflection, diagnosis, action plan and improvement. It should be noted that the application of the DAETE model to different contexts, purposes and situations showed that it can be extended to other applications in education and training. It is relevant to notice that it can be used for accreditation of centres and for training like shown in the case studies description.

The first recommendation is that the DAETE model should be experimented thoroughly in other educational and training environments to test efficacy and efficiency. The examples show flexibility and scope that can cover other organizations. It should be possible to extend the DAETE model to a whole institution and verify of quality improvement can derive from the assessment results. The second recommendation is that the DAETE model application requires external auditing to ensure independence of the assessment and identification of the improvement actions. Self-assessment may help the self-diagnosis and reflection but maybe the results will be biased by the nature of connection the respondent to the CEE centre. The third recommendation is that the DAETE model should adapt the choice of sub-criterion due to the nature of the context where the CEE centre operates. For instance, the CEE centre may be funded by public sources or it may be private. In the first case, the profitability may not be relevant while in the second it is fundamental. As conclusion the DAETE model may be a tool and process leading to excellence in education and training if properly used and interpreted.

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Appreciation goes to all that participated that were truly involved and interested in the cooperation in improving quality of CEE and in promoting better education and training. The special recognition is dedicated to late Prof. John Klus that was a reference in CEE, in general, but an effective leader and expert in the DAETE project (IACEE 2011). For him barriers in the project were to be surpassed and his training as a civil engineer probably played an important role in that behavior. That leadership and wisdom were particularly relevant while dealing with different academic and professional cultures and with the idiosyncrasies of the partners linked with the respective CEE contexts. He was fundamental to the conclusion of the project and to the successive steps that led to the dissemination and experimentation of the model. The European Commission and FIPSE also deserve appreciation for a project that was innovative and useful for quality of CEE and of education and training.

References Références Referencias

1. AALTO (2020, May 29), Aalto University. Retrieved from https://www.aalto.fi/en.
2. CACEE (2020, May 29). China Association of Continuing Engineering Education. Retrieved from http://www.cacee.org.cn/.
3. DAETE (2020, May 29). Development of Accreditation in Engineering Education and Training. Retrieved from http://daete.up.pt/sites/default/daete_old/index.htm.
4. DAETE2 (2020, May 29). DAETE [2] - International Continuing Education Program Benchmarking based on an EFQM Quality Process. Retrieved fromhttp://daete.up.pt.
5. EACEA (2020, May 29).EU-US Atlantis program. Retrieved from https://eacea.ec.europa.eu/sites/2007-2013/eu-us-atlantis-programme_en.
6. EFQM (2020, May 29). European Foundation for Quality Management. Retrieved from http://www.efqm.org.
7. FIPSE (2020, May 29). Fund for the Improvement of Postsecondary Education. Retrieved from https://www2.ed.gov/about/offices/list/ope/fipse/index.html.
8. IACEE (2011). John Klus remembrance. Retrieved from https://www.iacee.org/john_klus.php.
9. OE (2020, May 29), ACCEDE, Retrieved from https://www.ordemengenheiros.pt/pt/a-ordem/admissao-e-qualificacao/formacao-continua/.
10. QP (2020, May 29). Quality Program. Retrieved from https://www.iacee.org/quality_program.php.

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A Möbian Doppelgänger Theory: On Testing It

By Bogdan Ioan Nicula

Abstract- Here, we take the "cracked" version of the Snake Detection Theory (SDT) exposed in a previous study, and, while looking at it through the lens of some newly appeared studies, we proceed to investigate what it says in relation to how it could be object of (new) experimental study. While pointing that children with ASD(s), especially illiterate children with ASD(s) might be – or quite the opposite! – proper subjects for testing the "cracked" SDT, the surest best subjects are (still) found to be the (simply) illiterate ones.

Keywords: amygdala, ASDs, illiterate, snake detection theory, subcortical pathway, V2 Area, V4 Area.

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Strictly as per the compliance and regulations of:

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Keywords: amygdala, ASDs, illiterate, snake detection theory, subcortical pathway, V2 Area, V4 Area.

I. Introduction

In a recent study [1], we presented a "cracked" version of the SDT. The SDT [2] in its canonical form argues that:

- Due to their subcortical visual system connected to the amygdala and, also, to other (cortical) features, primates and, in particular, humans have keen perceptual abilities regarding the detection of snakes;
- The snake detection system relies mainly on spotting the angular and multilinear "camouflage" patterns, even when this design is masked by vegetation;
- We owe our stereoscopic vision to a common evolution of our ancestors and (some venomous) snakes.

The first question(s) should be: is the "cracked" version really better, more in line with the overall data, and solving more puzzles/ introducing more important ones? We wanted to address the soundest critical arguments looking at the SDT. Thus, we gave a new form to two of the original three points [1]:

- The effectiveness of human snake detection in real situations is not as great as according to the SDT [3];
- We have no objections to this (2nd) point;
- Stereopsis had emerged in many different taxa [4]: even if it's likely that the coevolution of our ancestors with poisonous snakes triggered various changes in the cortex and subcortex, stereopsis in humans being its output [5], there is still information that seems to point differently, even in an opposite direction [6]. Also, even if our ancestors entered in an arms race with some venomous snakes, this race should not be understood as ending with our victory. E.g., the role of the skin patterns in adders is not only camouflage, which we may "break" through, but also to confuse the mammalian eye through a flicker-fusion effect [7], and to inspire fear [7, 8]. As the arguments for the arms race go beyond the (reciprocal) modification of the visual systems [9], an arms race of reasonable proportions to be called as such is, in our opinion, plausible at best.

So, what is certain for us is solely the 2nd claim, according to which the angular and polylinear patterns are important for the subcortical processing of potentially deadly dangers. The "cracked" SDT takes from its "ancestor" the least speculative premises. Thus, it is not focused at all on the (co)evolution of our biological ancestors.

The SDT has recently passed some important tests for its macroevolutionary claims, everyone should acknowledge that. E.g., our pragmatic stance towards (what we call) the first point of the SDT proved to be wrong. A natural simulation showed the subjects' heartbeat always going up when aiming at the snake, and it made no difference whether the snake was or wasn't consciously perceived [10].

The essential differences between SDT and our "cracked" version will be listed further. Where our version differs in substance is in what it adds to the SDT, having included here the parts derived from the SDT, more exactly, from the details constituting the 2nd claim of the original SDT. So, let us proceed to describe synthetically our "cracked" SDT. We should see clearer what we can evaluate and how. Then, we can suggest proper experimental subjects.

According to those essential parts of the "cracked" version which are not shared with the original one, the subcortical visual passage involved in snake detection confuses artificial patterns, e.g., the characters in this article, with natural stimuli relevant for survival, e.g., the patterns of some venomous snakes, e.g., those of the Viperidae family. Experimental data shows that the subcortical visual system is alerted even if, or particularly if the snake patterns are partly occluded by vegetations. Many of the graphic characters, constituting angular and/ or polylinear formations would resemble dorsal patterns found in snakes, much more if presented in an occluded, interrupted manner. The fragmented patterns – and, as such, our theory goes, their formal siblings – initiate an alert state at the level of the right basolateral amygdala, i.e., the destination of the subcortical visual pathway. The passage is withdrawn from direct cortical control, an exceptional

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case of anatomical segregation, as tractographic data indicates. For such reasons, we have inferred, errors of the subcortical visual route would be virtually perpetuated indefinitely. Still, we should also expect two shifts regarding the perception of graphic characters. We start from the banal observation that the subcortical visual system can activate at various intensities, and from another type of observations, a topic explored in the paper, indicating that it is reasonable to expect the (right basolateral) amygdala endpoint of the pathway to "read" stimuli both as appetitive and/ or aversive – we may even conceptualize it as instilling maladaptive behaviour through enabling the instrumental pursuit of the appetitive stimuli, according to these data. Because we are dealing with resemblance rather than with correspondence, the intensity of the reaction should be lower. Yet also, as the resemblance is intriguing, appetition will largely replace aversion [1].

Now, we have arrived to the "juicy" part of our hypothesis. Light is a greater reducer of aversion/ enhancer of appetition, much better than sound. We have inferred from such data that, by promising greater chances of a happy-end encounter, light would increase the attractiveness of the graphic marks. It can be thus deemed a Pavlovian conditioned stimulus for attraction towards graphic characters. However, when using the route in a (more) luminous environment, we would reduce (at a faster pace) the intensity of the reaction, and this is how light becomes the main object of attraction: it compensates for the lower intensity of the stimulation induced by characters. The graphic characters will stay relevant even when becoming secondary, due to the anatomical and functional segregation of the subcortical system. The output deriving from a progressive attraction to light associated with fractured lines/ angular patterns/ multilinear patterns is likely the equivalent of a mass extinction scenario - at least, not unless (unforeseen and/ or powerful) "recoils" occur [1].

Joking a little, even if, now, it may seem inappropriate, you might say it is a möbian snake theory. We may not perceive when we, as individuals, or as a species, pass from that which is rather a longing for light-accompanied terrifying patterns to a "full-blown" addiction towards patterns-accompanied light. But why throw it fully on the snake? The addiction is not towards authentic snake patterns, but towards unacknowledged imitative representations. This act of imitation has some nasty repercussions (not to say the least), so we named the "cracked" version a/ the Möbian Doppelgänger Theory (MDT).

II. In Order to Test it

We were making a case for the plausibility of the MDT in our previous article. Its basis are the following observations:

1. When aiming at venomous snakes: coactivation of the subcortical visual route with the V2 plus V4 cortices, the latter two areas being known to possess neurons sensible to angular structures and fractured colinear segments (V2), respectively complex multilinear patterns (V4);
2. When aiming at achromatic diamond/ checkerboard patterns, isolated from the snake: idem, coactivation of the subcortical visual route and of the V2 and V4 areas;
3. When aiming at characters pertaining to writing systems with more complex aesthetics: coactivation of the V2 and V4;
4. When aiming at letters of (classical) alphabets: activation of the V2.

To these, we may add – yet, it should not be deemed an observation of the subcortical pathway activity:

5. When learning to read the Devanāgarī, an alphasyllabary which borders ideograms aesthetically: coactivation of two subcortical formations (the right superior colliculus, and the bilateral pulvinar nuclei) partially superposable with the subcortical route, together with V2 and V4 [1].

One may say: the participation of the subcortical visual pathway in reading is to be highly doubted. No activity of the third key-element of the subcortical route, the amygdala, was detected. But if we follow closely the MDT, it is precisely this activity which is the one that is harder to detect. The emotional reaction towards characters is supposedly reduced, first of all because of overall dissimilarities between the typical look of (fragmented) snake patterns and the graphic patterns. Now, if the activity in the bilateral pulvinar and right superior colliculus has something to do with the subcortical pathway, we should perhaps give a big "thanks!" to the very rare design of the study in question, because it involved illiterate subjects, because illiterates – maybe those from more oral communities particularly because selection towards less prominent snake reactions may have massively occurred in our literate societies since centuries/ millennia – may have comparatively (much) stronger reactions [1].

Thus, to better evaluate the MDT, we need to fulfil at least one of these three conditions in a similar experiment:

1. have more sensitive/ better (neuroimaging) tools;
2. the ambient is rather dimly lit;
3. the subjects have a strong subcortical vision in the presence of patterns of the mentioned types.

Regarding the first condition: we should expect difficulties when studying the human subcortex! This land asks for measuring very deep and very fast neural activity. Measuring such activity is difficult for the fMRI and the M/EEG approaches alike. As a general point, because of the methodological and interpretative boundaries pertaining specifically to the various approaches that may prove useful here, we can only recommend the comparative use of multiple approaches in order to better understand this domain [11]. On another hand, we can breathe easily: it is far easier to satisfy the second condition. Considering these, we find ourselves primarily concerned, for the moment, with the third condition. We will try to identify subjects that would be suitable for testing the MDT.

Subjects with autism spectrum disorder (ASD) or, if you prefer the plural, autism spectrum disorders (ASDs) – the debate looks far from being settled [12] – seem proper for testing our theory. ASD(s) clearly has/have a very strong genetical basis, one which is proved by studies on monozygotic twins [13]. Yet, ASD(s) is/are among the most genetically heterogeneous neuropsychiatric disorder(s) [14]. The structural differences in ASD(s) vary highly with age [15]. Despite all this heterogeneity, there is some order to be found even here. One object of interest for us is that amygdala neurons in children with ASD(s) consist of unusually greater numbers. The number of these neurons will decrease drastically with age. Adults with ASD(s) have much fewer amygdala neurons than neurotypical individuals [16]. Because of their great number of neurons in amygdala, children with ASD(s) may seem close to the ideal subjects for testing the MDT. We take notice that there are impairments in ASD(s) possibly impeding us to test the MDT in this manner, e.g., due to dorsal stream processing being disrupted, ASD(s) children need somatosensory feedback where watching would be enough (for learning) for neurotypical subjects [17]. So, before trying to (in)validate MDT, examining snake detection in ASD(s) children seems critical. It might be that illiterate [1] children with ASD(s) are ideal. Or, and that is our recommendation, that we should stick to studies on illiterate subjects. Taking into consideration the possible relevance of genetical selection, illiterate people from largely illiterate communities are ideal.

III. Conclusion

Both illiterates, especially those with a more traditional way of life, and children with ASD(s) are marginal in many (contemporary) societies. We usually expect scientific approaches to improve their condition, not vice versa. So, things seem to be reversed. We, as researchers, need to appeal to these people. It might sound even "worse": that, because, after weighing the plausibility of the MDT in correlation with the size of the problem the MDT is pointing out, scientific thinking may become a "suicidal" and "patricidal" tool, i.e., targeting the fundaments of science. We are thus in need of asking what will we do: go with the science, perhaps against it (and against much, much more)? Or, go with something that we call science to defend… exactly what?

References Références Referencias

1. [Nicula, B.-I. (2020). Cracking the Snake Detection Theory: The Subcortical Visual Pathway as a Major Player in Cultural Tranformation. World Journal of Neuroscience, 10, 166-190. 10.4236/wjns.2020.104018.
2. Isbell, L. A. (2009). The Fruit, the Three, and the Serpent: Why We See So Well? Harvard University Press, Cambridge & London. 10.2307/j.ctvjnrvj0.
3. Coelho, C.M., Suttiwan, P., Faiz, A.M., Ferreira-Santos, F. and Zsido, A.N. (2019). Are Humans Prepared to Detect, Fear, and Avoid Snakes? The Mismatch between Laboratory and Ecological Evidence. Frontiers in Psychology, 10, Article No. 2094. 10.3389/fpsyg.2019.02094.
4. Galloway, J. A. M., Green, S. D., Stevens, M., and Kelley, L. A. (2020). Finding a Signal Hidden among Noise: How Can Predators Overcome Camouflage Strategies? Philosophical Transactions of the Royal Society B, 375, 20190478, 10.1098/rstb.2019.0478.
5. Adams, W. J., Graf, E. W., and Anderson, M. (2019). Disruptive Coloration and Binocular Disparity: Breaking Camouflage. Proceedings of the Royal Society B, 286, 20182045, 10.1098/rspb.2018.2045.
6. Wheeler, B.C., Bradley, B.J. and Kamilar, J.M. (2011). Predictor of Orbital Convergence in Primates: A Test of the Snake Detection Hypothesis of Primate Evolution. Journal of Human Evolution, 61, 233-242. 10.1016/j.jhevol.2011.03.007.
7. Valkonen, J. K., Vakkila, A., Pesari, S., Tuominen, L., and Mappes, J. (2020). Protective Coloration of European Vipers throughout the Predation Sequence, Animal Behaviour, 164, 99-104. 10.1016/j.anbehav.2020.04.005.
8. Wüster, W., Allum, C.S.E., Bjargardóttir, I.B., Bailey, K.L., Dawson, K.J., Guenioui, J., Lewis, J., McGurk, J., Moore, A.G., Niskanen, M. and Pollard, C.P. (2004). Do Aposematism and Batesian Mimicry Require Bright Colours? A Test, Using European Viper Markings. Proceedings of Royal Society of London B, 271, 2495-2499. 10.1098/rspb.2004.2894
9. Harris, R. J., Nekaris, K. A.-I., and Fry, B. G. (2021). Coevolution between Primates and Venomous Snakes Revealed by α-neurotoxin Susceptibility, bioRxiv,preprint. 10.1101/2021.01.28.428735.
10. Jensen, C. H. and Caine, N. G. (2021).Preferential Snake Detection in a Simulated Ecological Experiment, American Journal of Physical Anthropology, preprint.10.1002/ajpa.24224.
11. McFadyen, J. (2019). Investigation the Subcortical Route to the Amygdala Across Species and in

Disordered Fear Responses. Journal of Experimental Neuroscience, 13, 1-4. 10.1177/1179069519846445.
12. Oberman, L. M. and Kaufmann, W. E. (2020). Autism Spectrum Disorder versus Autism Spectrum Disorders: Terminology, Concepts, and Clinical Practice. Frontiers in Psychiatry, 11, 484. 10.3389/fpsyt.2020.00484.
13. Tick, B., Bolton, P., Happé, F., Rutter, M., and Rijsdijk, F. (2016). Heritability of Autism Spectrum Disorders: A Meta-Analysis of Twin Studies. Journal of Child Psychology and Psychiatry, 57, 585-595. 10.1111/jcpp.12499.
14. Hodges, H., Fealko, C., and Soares, N. (2020). Autism Spectrum Disorder: Definition, Epidemiology, Causes, and Clinical Evaluation. Translational Pediatrics, 9 (suppl. 1), S55-S65. 10.21037/tp.2019.09.09.
15. Lin, H.-Y., Ni, H.-C., Lai, M.-C., Tseng, W.-Y. I., and Gau, S. S-F. (2015). Regional Brain Volume Differences between Male with and without Autism Spectrum Disorder are Highly Age-dependent. Molecular Autism, 29, 1-18. 10.1186/s13229-015-0022-3.
16. Avino, T. A., Barger, N., Vargas, M. V., Carlson, E. L., Amaral, D. G., Bauman, M. D., and Schumann, C. M. (2018). Neuron Numbers Increase in the Human Amygdala from Birth to Adulthood, but Not in Autism. PNAS, 115, 3710-3715.10.1073/pnas.1801912115.
17. Williams, J. H., Whiten, A., and Singh, T. (2004). A Systematic Review of Action Imitation in Autistic Spectrum Disorder. Journal of Autism and Developmental Disorders, 34, 285-299. 10.1023/B:JADD.0000029551.56735.3a.

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Myths, Misconceptions and Mistakes in the Electrostatic Protection of Field-Sensitive Items - Why it's Time to Re-Visit Device Protection

By Gavin Rider

Abstract- The measures currently being taken to prevent electrostatic damage in semiconductor manufacturing environments are not sufficient to guarantee the complete protection of items that are highly sensitive to electric field. Mistakes that have been made in the interpretation of electrostatic damage phenomena in manufacturing and errors that have been made in attempting to provide protection against them are described. It is shown that some of the ESD countermeasures in widespread use today can actually increase the electrostatic risk for field-sensitive items. The static dissipative materials that are commonly used to make pods and transport boxes are shown to expose field-sensitive items to a significant risk that can result in cumulative and permanent damage. It is concluded that more research into semiconductor device electrostatic damage mechanisms other than ESD is urgently needed, as has previously been called for by researchers studying the problem. It is also recommended that the electrostatic countermeasures being used in device manufacturing and handling should be reviewed and revised where necessary, to improve the protection of all extremely-electrostatic-sensitive (EES) items.

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MYTHSMISCONCEPTIONSANDMISTAKESINTHEELECTROSTATICPROTECTIONOFFIELDSENSITIVEITEMSWHYITSTIMETOREVISITDEVICEPROTECTION

Myths, Misconceptions and Mistakes in the Electrostatic Protection of Field-Sensitive Items – Why it's Time to Re-Visit Device Protection

Gavin Rider

Abstract- The measures currently being taken to prevent electrostatic damage in semiconductor manufacturing environments are not sufficient to guarantee the complete protection of items that are highly sensitive to electric field. Mistakes that have been made in the interpretation of electrostatic damage phenomena in manufacturing and errors that have been made in attempting to provide protection against them are described. It is shown that some of the ESD countermeasures in widespread use today can actually increase the electrostatic risk for field-sensitive items. The static dissipative materials that are commonly used to make pods and transport boxes are shown to expose field-sensitive items to a significant risk that can result in cumulative and permanent damage. It is concluded that more research into semiconductor device electrostatic damage mechanisms other than ESD is urgently needed, as has previously been called for by researchers studying the problem. It is also recommended that the electrostatic countermeasures being used in device manufacturing and handling should be reviewed and revised where necessary, to improve the protection of all extremely-electrostatic-sensitive (EES) items.

I. Introduction

If one asks any electrostatics expert working in the semiconductor industry about what must be done to eliminate electrostatic risk, the response will probably center on ESD and how to prevent it. This leads to discussion about the causes of ESD, which are primarily; a) the generation and accumulation of electric charge, and b) the bringing together of objects having a different charge balance during handling or processing. It follows logically that ESD prevention involves avoiding a) and b). First one must identify where such risk exists, then one must find a way to either counter or remove it.

Charge accumulation is most easily indicated by measuring the voltage of an object, and this is usually done with a high impedance voltmeter for conductive objects, or a hand-held field meter to measure the electric field emanating from insulating objects. In more detailed electrostatic investigations and factory audits, the level of excess charge held on an object may be measured directly with a coulomb meter or Faraday cup, the purpose of which is to estimate the current that is likely to flow in any discharge event and hence assess the risk of serious damage being caused by a discharge. This approach to risk assessment is embodied in SEMI Standard E78, "Guide to assess and control electrostatic discharge (ESD) and electrostatic attraction (ESA) for equipment" [1] and SEMI Standard E129 "Guide to assess and control electrostatic charge in a semiconductor manufacturing facility" [2] which are just two of many such guides that have been published.

It is necessary to have such standardized approaches to assessing electrostatic risk to ensure that different manufacturing sites can be assessed for electrostatic safety in a comparable way by different personnel, thus ensuring consistency throughout the supply chain. Electrostatic compatibility assessments are also carried out to qualify the production equipment that is to be used for making different generations of semiconductor devices, and each year the voltages and level of charge that are permitted within the manufacturing environment are reduced in line with the shrinking feature sizes of each production "node". Users expect that the certification of a piece of manufacturing equipment to the levels defined in an industry standard gives them assurance of the electrostatic safety of that equipment.

For a manufacturing site manager, receiving a pass result in an electrostatics audit is probably more important than understanding the nature of the electrostatic risks present in the facility. What the site manager needs is confirmation from an expert authority that it is safe to carry on production, which is why audits carried out by electrostatics consultants are extensively relied upon. The rationale behind this is that the person conducting the audit fully understands all the risks, and that those risks are being properly assessed in the tests being carried out.

Unfortunately, that is not always true [3] and the use of standardized approaches to risk assessment for certification purposes, whereby auditors focus on taking prescribed measurements and filling in forms to generate a pass or fail result, can risk them overlooking the diversity of electrostatic risks that may be present. Errors made in understanding the risks that are identified can also lead to ineffective or incorrect treatment, with the consequence that further unidentified risks can still be present.

The following sections identify some of the risks that can be missed in conventional electrostatic audits, some of the mistakes that have been made in defining

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'safe' handling practices for electrostatic sensitive objects, and some of the errors present in equipment designs and installations. Illustrations are given using reticles as a primary example (or with data from sensor devices developed specifically to study reticle handling risk) because reticles are extremely field-sensitive, they have been studied extensively and they provide clear illustrations of the risk created by electric field, which is invisible and can be difficult to measure electronically. The use of reticles and reticle-related data for these examples does not mean that the characteristics being discussed are restricted to reticles – these are simply presented as examples of how electric fields can behave – so for "reticle" read "any field-sensitive object". Electrostatics operate in the same way with everything.

II. Limitations of some Electrostatic Risk Assessment Methods

a) Charge accumulation

Methods for evaluating the electrostatic safety of a piece of production equipment are described in SEMI Standard E78. One of the tests involves measuring the amount of static charge present on a wafer or reticle as it leaves the equipment's load port. This risk assessment method assumes that the amount of charge found on the wafer or reticle when presented at the load port would indicate the likelihood of electrostatic damage being caused to it by the equipment, or by its subsequent handling. This is not necessarily true, however. If a wafer or reticle's insulating surface becomes charged within a piece of equipment, subsequent grounding of the reticle's conductive film or the wafer substrate during handling can result in the attraction of a balancing charge onto it from ground.

A hypothetical scenario is illustrated schematically in Fig 1, wherein a vacuum gripper contacts the upper surface of a reticle to move it. In accordance with the established practice in the semiconductor industry, the reticle support points at the hand-off position are made from grounded static dissipative material. A balancing charge would be drawn onto the conductive part of the reticle from ground through the support points, attracted by the static charge on the upper surface created by the vacuum gripper. An electric field would then be present between the two opposite charges on the reticle and this could induce damage in the reticle's pattern area.

However, if a reticle in this condition were removed from the equipment and the amount of charge it carries at the load port measured using a Faraday cup, the result would be close to zero because the static charge had been balanced by grounding the reticle inside the equipment. The equipment would pass the E78 safety assessment and hence be considered "safe" – despite the fact that reticles could be damaged while inside it.

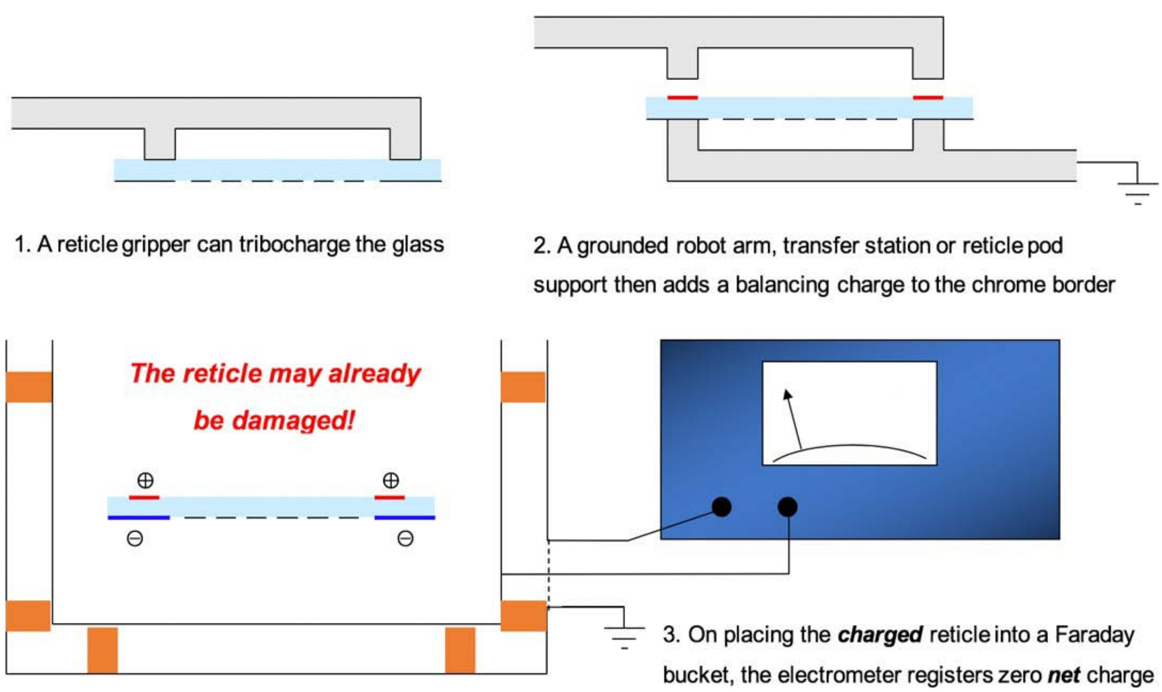

Fig. 1: Charging of a reticle within a piece of equipment (or an insulating layer on a wafer, which could also result from a processing operation) followed by the addition of a balancing charge to a conductive part by a grounded handling tool. On removal from the equipment a measurement of the charge held on the tested item, as defined in SEMI Standard E78, would measure little or no net charge, incorrectly indicating the 'safety' of the equipment.

A similar situation could arise in wafer handling, if a processing operation charged an insulating layer on the upper surface of the wafer and the substrate was grounded through an equipotential bonding scheme being used on the material handling system.

Other risks than those caused by the charging of a sensitive item with static electricity can occur inside equipment. Electrostatic damage to reticles has been shown to occur through field induction even when there is no charge transfer to or from the reticle. A reticle can suffer ESD damage through exposure to an electric field while remaining electrically neutral – the reticle does not even have to be touched for damage to occur. This is the predominant electrostatic risk for reticles during normal use. It is described and guidance for avoiding it is given in SEMI Standard E163 [4]. The risk to a reticle from field induction cannot be assessed by measuring the charge the reticle holds at a load port, it is better assessed by using a specially configured sensor device [5] that can go where a reticle goes inside the tool and can record the electric field conditions that a normal reticle would experience. Examples of this will be shown.

b) Tribo-charging of carriers

Technical errors have been made in attempting to reduce the electrostatic risk to reticles caused by the tribo-charging of reticle pods and storage boxes during manual handling. When the first single-reticle boxes were made they were molded from insulating plastic such as polycarbonate, which has the advantage of being crystal clear so the reticle inside can be identified without opening the box. It was subsequently found that handling of the boxes could tribo-charge them to a very high voltage (up to 50kV) and when they were opened on a piece of equipment to remove the reticle, the electric field became concentrated between the charged box and the grounded load port, passing directly through the reticle and causing ESD damage. Alternative materials were sought that would not tribo-charge to the same extent, and modifications were attempted to try and improve the performance of existing pods (which will be described later).

Investigations into the suitability of alternative materials for making reticle pods measured how much they would be charged by handling, which was done by performing a "wipe test". In this test, a sample of the material under investigation is rubbed vigorously with either a cloth or a cleanroom glove, and the degree of tribocharging is then determined by measuring the electric field the material generates, as described in SEMI Standard E43 [6]. Static dissipative plastic materials were found not to exhibit persistent electric fields when tested in this way, so it was decided to make reticle pods from static dissipative rather than insulating plastic.

This change, when introduced alongside other static-reduction measures in reticle handling areas, resulted in a significant decrease in the rate of reticle ESD damage. However, changing the pod material only addressed the specific risk being caused by the pod itself first being charged by handling, then being placed onto a grounded load port or other surface. Other risks remained, and these new materials actually introduced some new risk, as will be described later.

It became a common belief, as a result of using "wipe tests" to evaluate materials for electrostatic risk in this way, that static dissipative plastics do not tribo-charge. This is a dangerous misconception, since all materials can be tribocharged. What was actually being measured in a wipe test was the ability of the tested material to *retain* the static charge on its surface for a long time. Static charge is generated on the surface of dissipative material by friction, but the charge then spreads out across the surface, reducing the strength of the electric field it produces. If the material is grounded the excess charge is drained away within a few seconds leaving no electric field to be detected.

Typically, it would take several seconds for a field reading to be taken in a wipe test, so any field generated on a dissipative test material by tribocharging would have diminished or even disappeared by the time the readings were taken. Since a reticle can be damaged by an electric field within nanoseconds, this assessment method is not temporally sensitive enough to detect the risk that static dissipative material actually presents to a reticle. Just as with the "retained charge" test in SEMI Standard E78 giving a false impression of safety as illustrated in Fig 1, passing a wipe test falsely indicated the electrostatic safety of static dissipative material, and incorrectly indicated its suitability for the construction of reticle pods and storage boxes. Experimental confirmation of this will be described later.

c) Inductive charging of ESDS items

Small but important errors are sometimes made in the assessment of electrostatic risk in manufacturing processes. One commonly made mistake is in the description of discharges that can occur when using pick-and-place equipment to remove individual die from diced wafers, to place devices into circuit boards or to insert devices and circuit boards into testing stations. It is sometimes described that when an object is handled in the presence of an electric field it becomes charged by field induction, and that if it is subsequently brought close to a grounded conductor (e.g. when placing a packaged device into a circuit board or tester) it can be discharged. An example describing CDM risk in this way is mentioned in in Chapter 3 of the Industry Council on ESD Target Levels' White Paper 2 [7], which says:

"A typical example for this is the In-Circuit-Test (ICT). The PCB is pressed down by plastic pins made very often of highly chargeable material. This charging is transferred to the PCB by induction. During the electrical measurement the PCB is contacted with metallic Pogo-Pins and a hard discharge from the PCB into the tester can occur."

This is a physically incorrect description of the phenomenon. What is actually happening in such a scenario is similar to the example shown in Fig 1, except that in this case the charge is present on the plastic pins used to hold the board in the tester, rather than being present on the board itself. The board cannot be charged by induction as described in the white paper because it is an insulating substrate and the charged plastic pins that hold down the board are also insulating, so no charge can be transferred between the two. Rather, the electric field from the charge on the plastic pins attracts a balancing charge from ground, so that when the tester contacts the circuit board connectors through the pogo-pins, it is the transfer of this balancing charge into the circuitry – not the discharging of the inductively charged board – that causes the CDM event.

This may seem like undue pedanticism to some, but correctly understanding such events and describing them accurately is essential for controlling the associated risks. The white paper makes the following observation after giving this example:

"Very critical during such "closed" process steps is the fact that the problem can be overlooked very easily since the PCB is not charged before and after the process but can nevertheless be damaged during the process".

The conclusion that the board would not be charged after this process is incorrect. Only *after* the "discharge" has taken place through the pogo pins is it correct to say that the board has been charged by field induction. If the electrical connection to ground through the pogo pins is broken before the circuit board is removed from the electric field being generated by the charged plastic clamping pins, which is highly probable, the circuitry will retain the balancing charge that was added to it from ground. Moving the circuit board away from the charged plastic pins on the tester would leave it in a *charged* state, so the board could suffer another CDM (or more correctly, a "charged board") event when next connected to ground at another processing station.

It is essential when defining how to deal with the risk created by such processes to correctly identify where the excess charge is located. In the example of Fig 1 the charge on the object is on an insulating surface, so it cannot be removed by grounding the object. In this example of the inductive charging of a circuit board at a test station, the excess charge is present within the circuitry itself, so it can be removed by grounding the contact pins.

If grounding is used inappropriately as a universal way of trying to prevent objects from carrying excess charge, as it often is within the semiconductor industry, there will probably be many situations like the one shown in Fig 1, and it is not guaranteed that all objects being treated in such a way would be undamaged by it.

The white paper includes another incorrectly assessed example, this time describing the risk from the charging of an ESD sensitive component by a vacuum cup used in a pick-and-place tool. Fig 2 is a section from a series of examples given in the white paper describing electrostatic risks in a semiconductor manufacturing environment.

Possible Risk	Test Method	Remedy
ii) The ESDS gets charged due to the use of ungrounded or insulative suction cups at pick and place and discharges into the board	a) Measure the charging of the IC while it is hanging on the suction cup b) Measure the charging of the suction cup Measure the resistance to ground of the suction cup	Use conductive/ dissipative suction cups, that are grounded; if necessary, use an ionizer to reduce the charging

Fig. 2: Description of the electrostatic risk associated with pick-and-place equipment that inserts an ESDS device into a circuit board, reproduced from [7]

The description of this risk is not completely correct. If the suction cup is an insulator, it cannot transfer a significant amount of any charge it holds to the ESDS item, because any charge it holds will be trapped on its insulating surface. It can charge the ESDS item by field induction if the ESDS item contacts a grounded conductor while it is exposed to the electric field from the charged suction cup. As in the previous example of the charging of a circuit board by a circuit tester, the ESDS item would become charged by induction when it is grounded by being inserted into the board, it would not be discharged by this step.

The most critical factor in the use of suction cups for pick-and-place operations is the ability of the suction cup to tribo-charge the object being handled, as shown in the example of Fig 1. The degree of charging is dominated by the separation within the tribo-electric series of the different materials of the object and the suction cup that come into contact under pressure; it is not affected by the conductivity of the suction cup. Even metals can be tribo-charged and can tribo-charge other materials. The conductivity of the cup material only affects the time for which any excess charge that is created on its surface by tribo-charging will remain in place.

Since any tribo-charging of the ESDS item becomes permanent the moment the suction cup releases it (assuming that the part of the ESDS item contacted by the suction cup is insulating or electrically isolated, for example the encapsulation) then the fact that the charge on the suction cup could subsequently drain away to ground after separation would not change the risk to the ESDS item created by its tribo-charging during the handling process. A field meter measurement of a conductive or static dissipative suction cup after the ESDS item has been separated from it would show no remaining electric field, but it would not indicate that no tribo-charging of the ESDS item had taken place and therefore it would not be correct to conclude that the ESDS item was safe.

The confusing effect of using grounded handling tools is difficult to appreciate in such scenarios if one is relying on field meter measurements to assess the risk. This can be appreciated by considering the following description of the use of a static dissipative suction cup to place a device into a tester socket.

The suction cup tribo-charges the upper surface of the device encapsulation due to friction between the cup and the encapsulation as the vacuum is applied and released. At the moment of separation there will be an electric field present between the two separated charges. As the suction cup retracts from the device that it has just placed in the tester, the charge on the encapsulation would attract a balancing charge into the device circuitry through the connections to the tester. On completion of the test, the device would again be picked up by the static dissipative vacuum cup, which by now would be electrically neutral. The device in the tester would contain balanced charge, so there would be little external field present to attract a balancing charge towards the device through the suction cup. The device would then be disconnected from the tester and moved to its next destination, still holding the static charge on its surface and the balancing charge within the circuitry. This second handling step would create more tribocharging of the device due to the friction between the cup and the encapsulation, so on next grounding the device a further amount of balancing charge would be drawn into it. Hence, the repeated pick-and-place steps would effectively be equivalent to the repeated rubbing that is used to generate as much static charge as possible in a "wipe test".

Each handling step between equipotential-bonded stations would build up more charge, increasing the internal electric field strength between the charged encapsulation and the balancing charge drawn into the circuitry from ground. Yet because of the grounding of the device, which draws into it a balancing charge, any field measurement of a device experiencing such a handling sequence would register little or no external electric field, thereby conveying a false impression that the device was not being charged by the procedure.

III. Limitations of some ESD Prevention Methods

The primary focus of most electrostatics advisors working in the semiconductor industry is on ESD and its prevention. (There is also parallel activity focused on controlling electromagnetic interference, which is in part related to ESD suppression). A fundamental component of virtually all ESD and EMI reduction programs is electrical grounding, with appropriate standards being defined for the inherent conductivity and resistance to ground of all things used in the factory, from the flooring materials to equipment panels, conveyors and the clothing worn by operators. Electrostatic control has become an industry of its own within the semiconductor industry, because of its importance.

The standard approach taken to control ESD in the semiconductor industry is quite simple and easy to understand:

- Eliminate all non-essential insulators because they can accumulate static electricity
- Neutralize all essential insulators using methods such as air ionization
- Connect all conductive objects to a common electrical potential, normally ground (which is a procedure known as "equipotential bonding").
- Personnel working within a factory are required to wear conductive clothing and to be connected to ground, either through conductive footwear or by a special grounding strap worn at a workstation.
- Workstations are required to be grounded, to have static dissipative work surfaces and to have supplementary methods of charge neutralization, such as ionized air showers.

While these methods do successfully control many electrostatic-related problems in manufacturing, they are targeted specifically at ESD prevention rather than device damage prevention. An assumption behind this approach to the problem is that if you eliminate ESD by managing the conditions that cause it, devices and other electrostatic-sensitive items being handled in the controlled environment will be adequately protected. Unfortunately, that is a slightly over-simplistic view to take. Eliminating damage due to ESD achieves only partial protection.

a) Equipotential bonding

A brief indication of the confusion that can be caused by using equipotential bonding has already been given in the previous section. Additionally, equipotential bonding can be positively harmful if applied inappropriately, so it is essential to correctly understand the effect it is having and to only use it in an appropriate way. Using it routinely for the handling of ESDS items is not always appropriate.

When reticle electrostatic damage reached epidemic proportions in the late 1990s, the described principles of ESD control were applied to reticle handling in an effort to prevent the losses. The initiative succeeded in bringing down damage rates significantly, but reticle electrostatic damage did not cease completely; some semiconductor facilities were still experiencing extremely serious reticle damage problems.

In one example reported privately to the author, damage to a particularly sensitive production reticle had caused a loss of over $1 million in scrapped inventory and reticle replacements, despite the facility being equipped with the most advanced ESD countermeasures available and having frequent electrostatic audits. Every time a damaged reticle was replaced and the production line was purged of the defective wafers that had been printed with it, within a few weeks the same damage was experienced with the replacement reticle and more inventory had to be removed from the production line and scrapped.

Research at International Sematech had already demonstrated that field induction causes electrostatic damage in reticles without any conductive ESD taking place. Through computer simulation, it had been shown that grounding a reticle to protect it against conductive ESD during handling makes it more sensitive to electric field-induced damage [7], [9]. So this indicated that the adoption of equipotential bonding for reticle handling as part of the countermeasures defined above [10] was having the opposite effect to that which had been intended. Rather than helping to protect reticles, it was making the risk of field-induced electrostatic damage worse.

In the facility described above, wherein ESD was being effectively managed but electrostatic risk had not been completely removed, the damage being caused to the reticles was impossible to associate with any particular process or handling procedure; the risk was distributed everywhere, but it was either below the level considered to be hazardous or was not detectable by the methods being used in the electrostatic audits.

Initially, the conclusion drawn from the computer simulation study indicating the harmful effect of equipotential bonding was challenged by several electrostatics consultants who were working in the semiconductor industry, as their practical experience indicated to them that grounding is protective. This opinion seemed logical because reticle damage rates had fallen significantly after equipotential bonding was recommended for reticle handling, and the use of equipotential bonding had been known for a long time to improve semiconductor device yields.

Nevertheless, independent experimentation carried out by several research groups confirmed the indications of the computer simulation [11], [12], demonstrating conclusively that grounding makes the risk of reticle damage worse and it increases the severity of any field-induced damage that does occur. This indicates that field induction is a complex subject that can confound even highly experienced ESD practitioners.

It also shows that the reduction in reticle ESD damage rates had actually been achieved through a variety of other electrostatic countermeasures being taken at the same time, which had succeeded in reducing the overall electrostatic risk to a level where the effect of the error in using equipotential bonding was not observed. However, as was proven by the $1 million loss event, the remaining risk (which is made worse by the inappropriate use of equipotential bonding) can have much more serious consequences than the ESD risk that was being focused on in the electrostatic audits.

One other negative consequence of using equipotential bonding for the handling of electrostatic sensitive items is that it reduces the effectiveness of air ionization systems. Ionizers offer the only practical way of neutralizing a charged insulator in a semiconductor manufacturing environment. An ionizer injects a balanced flow of positive and negative ions into the air, then the electric field from any charged object close by will attract ions of the required polarity to achieve neutralization, while ions of the opposite polarity will be repelled. It is necessary for the electric field from a charged object to attract the required airborne ions and repel the others in order to achieve charge neutralization, but if the object is grounded through an equipotential bonding scheme as illustrated in Fig 1, the charge it contains becomes balanced and it produces no significant electric field (other than the short-range internal field between the balanced charges it holds). Hence, by eliminating the external electric field from charged objects, equipotential bonding reduces the ability of ionizers to neutralize them.

It is often said in defense of equipotential bonding that it is the only practical way of removing static charge from items being manufactured in a production environment, where speed of material handling is essential for productivity. Grounding achieves *charge balance* relatively quickly (orders of magnitude faster than air ionization can achieve *charge neutralization*) which is why it is valued so highly by equipment makers and semiconductor manufacturers alike. But, since any static charge on a typical electrostatic-sensitive object being handled in a semiconductor factory is likely to be located on an insulating part of the object, such as the encapsulation of a packaged semiconductor device, the substrate of a circuit board or an insulating layer on a wafer, it cannot be removed by grounding. Connecting any conductive part of the object to ground can only introduce a balancing charge. This results in the object holding no net charge, so there will be no ESD if it contacts another grounded conductive object, but the object is not electrically neutralized by grounding it – it is put into an energized state rather like a charged capacitor, with energy stored in the internal electric field between the separated charges. If the object contains field-sensitive structures, this internally concentrated electric field can potentially cause damage, as it certainly does to reticles.

It is important to recognize that electric fields are vectorially additive, so even if the internal electric field produced by grounding a charged device during handling is not itself sufficient to cause damage to the device, its presence during testing or when power is applied during normal use could raise the total electric field within the device to a dangerous level – so this issue should not be ignored.

The desire for speed in material handling may need to become a secondary consideration in order to prevent extremely electrostatic-sensitive items from being damaged. An example of unavoidable charging by a process, which limits the speed with which the item can be handled when using equipotential bonding, is the cleaning of a reticle. Washing with deionized water and spin drying produces a large static charge on the surface, as shown by the measurement in Fig 3. This is a recording of electric field taken by the specially designed sensor device [5] mentioned in section 2, which has the same form factor as a normal production reticle and can pass through many of the processes that a standard production reticle would experience.

Internal field-measuring electronics continually record the electric field that the device is exposed to, then the stored data are downloaded to a computer for processing after the measurement is complete.

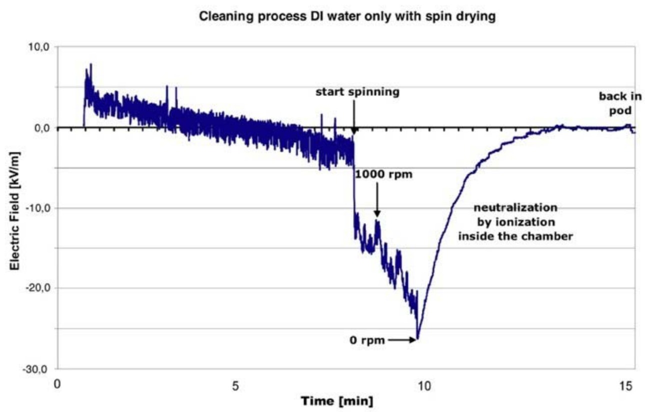

Fig. 3: Electric field recorded during reticle washing with deionized water followed by spin drying. Ionization to neutralize the reticle is essential after such a process, preventing the reticle from being moved until the static charge has been eliminated.

The static charge generated on the reticle by the process cannot be safely removed by equipotential bonding, as will be illustrated in the following subsection, which means that the cleaning procedure has to incorporate a throughput-limiting charge neutralization step, which requires five minutes in this example. Other production processes involving devices and semiconductor wafers, if subjected to equally stringent analysis of the electrostatic risks inherent in the process, may also be found to have a similar requirement for the safe removal of static charge by air ionization before further handling, rather than relying on equipotential bonding.

The conclusions drawn from this analysis are somewhat alarming, considering the trust that is placed in using equipotential bonding as a protective practice within the semiconductor industry:

- Grounding a charged object is unlikely to neutralize it unless it is homogeneous and conductive
- Grounding a charged object is likely to create an internal electric field between balanced opposite charges
- Grounding a field-sensitive electrically neutral object makes it more susceptible to field-induced damage
- Grounding reduces the effectiveness of air ionization, the only practical way of neutralizing an insulator

Equipotential bonding definitely reduces conductive ESD during material handling, by ensuring that objects always carry balanced charge, but it is neither inherently safe nor protective to use it with any field-sensitive object. ESD suppression through equipotential bonding does not necessarily achieve complete device protection and it can have the opposite effect to the one intended, by enhancing any risk arising from field induction.

b) Air ionization

Air ionization is the most practical way of removing static charge from insulators in a semiconductor factory, but it has been explained why it is not a guaranteed way of neutralizing static charge if used in combination with an equipotential bonding scheme. Air ionization also has some potentially negative attributes.

Most types of air ionizer used in semiconductor factories generate ions by applying a high voltage to a sharp electrode. This creates a high field strength at the tip of the electrode and this ionizes air molecules, which are subsequently repelled from the electrode by the electric field. It is evident from this description that many air ionizers generate intense electric fields in order to work. It is essential that the electric field generated by such an ionizer cannot reach a field-sensitive object, otherwise the object could be damaged by the very device that is installed to protect it. This potential damage scenario is regrettably not rare.

In the measurement shown in Fig 4, the sensor device [5] was loaded into a piece of reticle handling equipment fitted with an air ionizer in the load port area to neutralize any charged incoming reticles. Unfortunately, this ionizer had been installed much too close to the reticle handling path and the pulsed field from the ionizer tips could reach the reticle as it passed underneath. Every pulse of electric field from this ionizer recorded by the sensor reticle was capable of causing irreversible and cumulative damage to a production reticle.

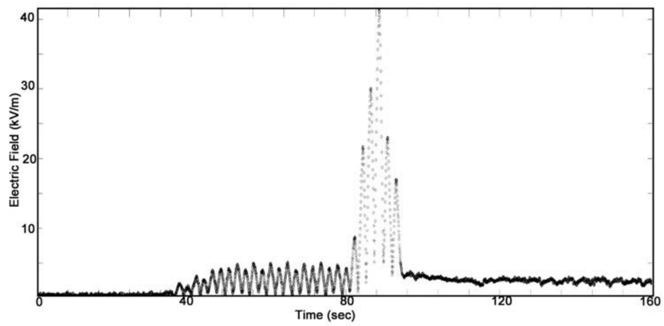

Fig. 4: Electric field recorded by a sensor reticle introduced to a piece of handling equipment fitted with an ionizer that is too close to the reticle handling path. As the reticle passes by the ionizer it experiences a rapidly oscillating field, each transient of which is capable of causing EFM degradation of the reticle [7], [14], [15], [21], [22], [23]}

Furthermore, as is shown by the offset in the reading after the reticle had passed beneath the ionizer, the ionizer had actually charged the surface of the reticle, leaving it susceptible to further damage as a consequence of subsequent handling with grounded robot arms. A similar observation was reported by Turley in an evaluation of the static control measures being used in a reticle manufacturing facility [13].

For correct operation it is essential that the ionizer is maintained to keep its output in a balanced condition, since contaminants in the cleanroom air can build up deposits on the ionizer tips that affect the ion production efficiency, leading to unbalanced ion emission. As mentioned by Turley [13], correct positioning of an ionizer is also essential to ensure that balanced ion streams can reach the target. If ionizer imbalance happens or an ionizer is badly positioned, it can add static charge to any object that passes nearby, which is demonstrated by the measurement shown in Fig 5.

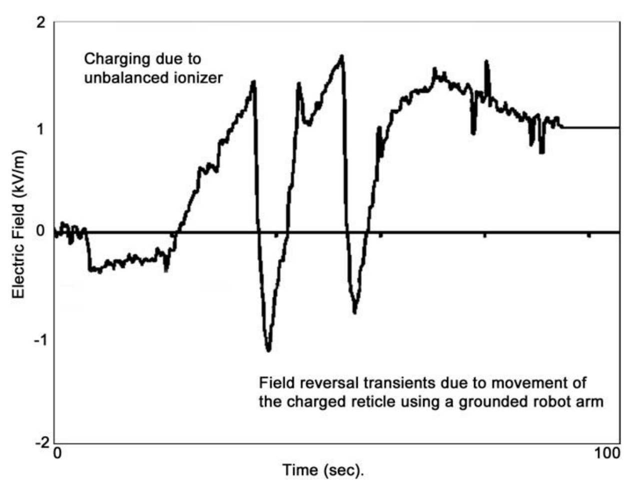

Fig. 5: Electric field recorded by a sensor reticle introduced to a piece of reticle handling equipment having an unbalanced ionizer and equipped with a grounded reticle handling robot (presumably fitted with static dissipative reticle contacts).

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As the sensor reticle in Fig 5 enters the equipment it is bathed in the unbalanced ion output from a badly maintained or poorly located ionizer, which charges the reticle surface to the same extent as shown in Fig 4. Subsequent handling of the reticle by a grounded robot arm, which is probably intended to safely remove any charge through static dissipative contact pads, results in rapid field reversals within the reticle. It can be seen that after each of the two handling steps the reticle has not been discharged.

The use of a grounded handling tool in this instance has created a significant risk of damage, by causing rapid transient field changes within the reticle. Every time the field conditions experienced by a reticle change, irreversible and cumulative damage can be caused, with transient field reversals of this kind being particularly hazardous [14], [15].

If the reticle cleaning station illustrated in Fig 3 was loaded and unloaded using a similar grounded robot arm, and if sufficient time was not allowed for charge neutralization to be achieved by air ionization before the reticle was removed, transient field reversals ten times stronger than those shown here would occur. The fields recorded in Fig 4 and Fig 5 are well above the level that could cause cumulative reticle damage, but these are not extreme examples. The reticle charging reported by Turley [13] as a consequence of a badly positioned ionizer was ten times more severe than in the examples illustrated here, making it comparable to the charging shown in Fig 3 arising from reticle cleaning.

While ionizers may indeed be the only practical way of dealing with static charge on insulators in a semiconductor manufacturing environment, they are certainly not fail-safe when being relied upon for the protection of field-sensitive items. When combined with an equipotential bonding scheme they can be rendered ineffective, and when used under conditions similar to those illustrated here they can be extremely hazardous.

c) Static dissipative and "conductive" plastic boxes

It was mentioned in section II that static dissipative boxes (also known as pods or FOUPS) have been found to be less protective than they were originally believed to be. Very soon after static dissipative single reticle pods were developed, testing showed that they are incapable of effectively shielding reticles from externally generated electric fields [16]. Because it had already been shown through experimentation at International Sematech that reticles can be damaged by field induction, this revelation should have resulted in the adoption of alternative reticle handling solutions that offered reticles adequate protection from electric field. However, the reduction in reticle ESD damage rates after the introduction of these new static dissipative reticle pods (alongside the complementary electrostatic countermeasures as already described in IIIa) gave the semiconductor industry the incorrect impression that the pods were working as intended and were adequately protecting their reticles, so they have subsequently been adopted the world over.

Reticle pods that were claimed to be electrostatically protective by providing a conductive path from the reticle to ground were developed by several makers wishing to capitalize on the standardization of reticle handling through the SEMI Standards, and pod designs based on this concept have become widely adopted. Fig 6 shows an extract from a reticle pod patent [17] that includes claims of the protective quality of the design, based on the belief that equipotential bonding safely removes static charge from charged objects such as reticles. The patent describes the prior art as requiring static dissipative contacts with the reticle to provide grounding through the pod door, but identifying that the static dissipative additives available at that time when added to the plastic of the box shell made the material cloudy, so the reticle could not be viewed. In this patent the grounding is provided via the support structure rather than through the pod shell, so the shell is made from transparent non-dissipative (i.e. insulating) material to provide improved visibility of the reticle inside the pod.

Grounding a reticle in this way increases the risk of electrostatic damage, and increases the severity of any damage that may be caused to a reticle carried inside such a pod [7], [11], [12]. Making the pod shell from field-transmitting material and grounding the reticle is a significant technical error, which is also made in another reticle box patent that claims to be protective [18], so this is not an isolated case of the misunderstanding.

Cheng et al [19] describe a modified reticle pod with embedded and/or externally applied metallic panels that are intended to shield the reticle from electric field, such as that arising from static charge generated on the pod handle by manual handling. However, these "shields", and the metal plates added to the top of single reticle pods for automated handling in reticle stockers, actually increase the field-induced reticle damage problem as shown by the computer simulation of Fig 7.

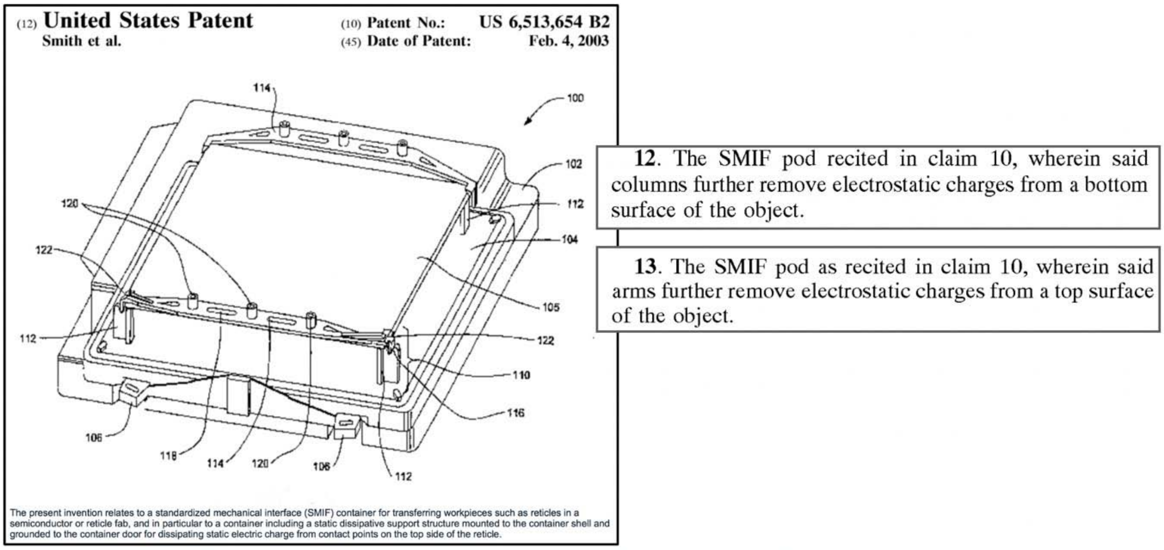

Fig. 6: An example of a reticle pod patent that claims to be electrostatically protective but which will actually have the opposite effect to that claimed. Grounding of a reticle in this way will increase its susceptibility to field-induced damage and cannot remove static charge from the reticle in the way claimed in the patent (refer to Fig 1).

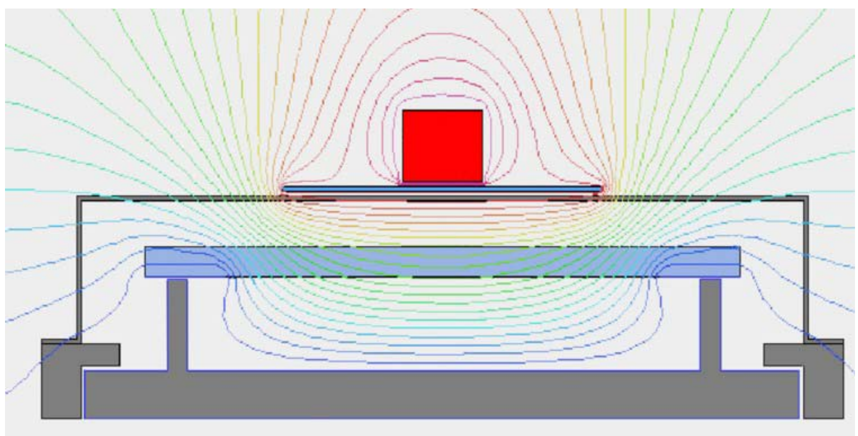

Fig. 7: Computer simulation of a reticle pod with a grounded static dissipative door and reticle supports, that has a metal panel inserted between the handle and the top casing of the pod in an attempt to shield the reticle from static charge generated on the handle, as described in [19]. The metal panel increases the electric field strength experienced by the reticle by perturbing the electric field, which is the opposite effect to that intended.

Metallic shielding in the form of a Faraday cage needs to be continuous and to completely enclose the protected item, as is well known from studies of EMI prevention. Modifications of reticle pods in the way illustrated in Fig 7 were carried out in an attempt to simultaneously overcome the ESD damage problem caused by reticle pod charging while avoiding the cost of replacing existing reticle pod inventories with much more expensive static dissipative alternatives. Such "in-house" modifications and pod redesigns were ineffective for the reason illustrated in Fig 7. Consequently, in the belief that the claims of reticle protection made by their manufacturers (as described in the cited patents) are true, most single reticle pod users have adopted static dissipative pods and boxes, which have now become a *de facto* standard in semiconductor production. All these attempts to provide electrostatic protection fail because of fundamental errors in the understanding of the risk.

The significance of making such errors in reticle pod design becomes apparent when one considers the extent of tribocharging of a reticle pod during normal handling and use. It was believed on the basis of the wipe-tests carried out to simulate the tribo-charging of a pod during manual handling that static dissipative materials do not tribocharge, hence their use for the construction of reticle pods should eliminate the pod charging problem and the ESD damage that it causes.

However, it has been shown that this is a misconception, as static dissipative plastics actually do tribo-charge quite efficiently.

If one uses a field sensor with sufficient sensitivity and temporal response, one finds that static dissipative pods generate and transmit to the interior a great number of intense electric field transients, even when they are being carefully handled in static-controlled semiconductor production environments. An example of this is shown in Fig 8.

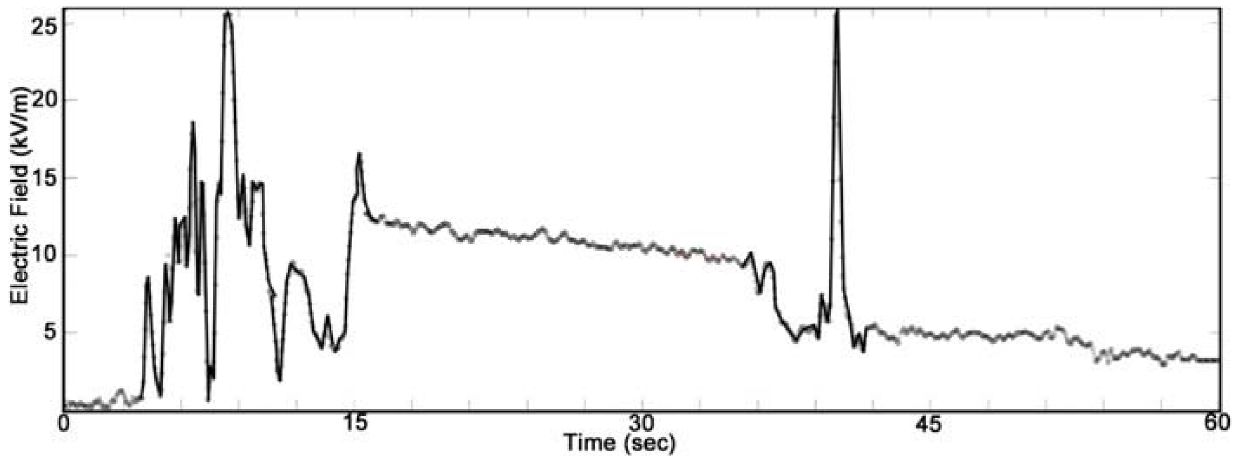

Fig. 8: Electric field recorded by a sensor reticle [5] while being handled normally in a standard static dissipative single-reticle SMIF pod in a semiconductor production facility equipped with all the standard electrostatic countermeasures, including air ionization, grounded operator clothing and footwear, conductive flooring etc.

Transients and high frequency fields are potentially highly damaging to reticles, as is explained in [15]. Static dissipative materials generate transient electric field pulses through normal handling, as demonstrated by the recording in Fig 8. They also convert constant external electric fields into internal field transients, doubling the damage risk; and they act as high-pass filters, selectively allowing rapidly changing external electric fields to penetrate – which means that they are definitely not ideal materials to use for the construction of reticle pods and boxes.

Being aware that reticle electrostatic damage was still happening inside static dissipative reticle pods, despite the adoption of all the recommended protective measures, Helmholz and Lering [12] conducted experiments to measure how much the protection provided by a reticle pod could be improved by increasing the conductivity of the plastic, from static dissipative to "conductive". By this time the desire to have a transparent case for the reticle so that it could be visually identified, as mentioned in the reticle pod patent [17], had been replaced by the urgent need to eliminate costly reticle electrostatic damage.

Helmholz and Lering showed that as the conductivity of the plastic pod shell was increased, the field-shielding effect was improved. But when they tested a pod constructed from the most conductive plastic material available (carbon nanotube loaded PEEK) a test reticle stressed inside it by exposure to an externally generated electric field suffered ESD damage.

Pernicious electrostatic damage mechanisms other than ESD take place at an electrostatic stress level orders of magnitude weaker than that which causes ESD in a reticle [20], [21], [22], [23], but their study did not evaluate the ability of the pods to suppress these. If a "conductive" plastic reticle pod was found to be incapable of preventing ESD damage to a reticle stored inside it, it certainly would not be capable of protecting a reticle against these other damage mechanisms.

Helmholz and Lering also confirmed that the damage sustained by the reticles in their test pods was increased by grounding them, as is confirmed by the results from their paper which are reproduced in Fig 9.

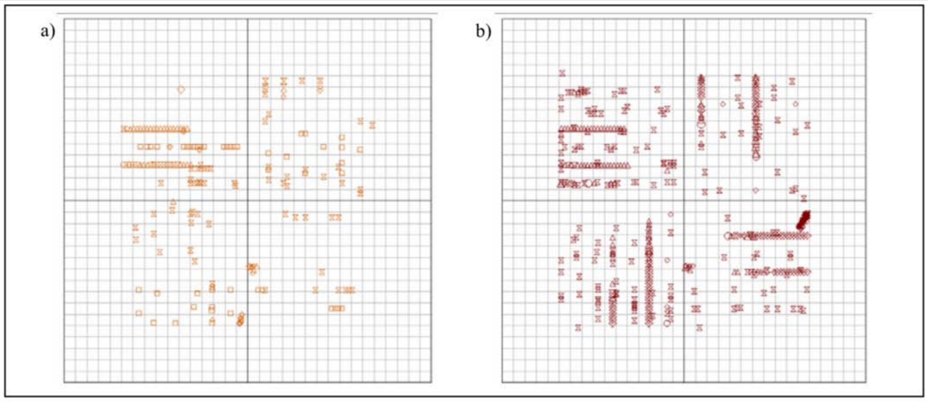

Fig 4 STARlight™ defect maps of ESD damages on a reticle held on a)insulation and b) conductive supports.

Both reticles were inspected on the STARlight™ mode on a KLA-Tencor mask inspection system after the tests, the results a displayed in Fig 4. Even though the reticle used in the experimental setup for isolating reticle contact points has been exposed to a much higher ESD challenge (20,000V highest voltage and 25 cycles of tests) the reticle shows much less ESD damages than the reticle used in the setup for conductive reticle contact points. A quantitative comparison cannot be made since the experimental setups were no the same, but qualitatively there is a clear picture: isolating reticle contact points greatly reduce the risk of ESD damages.

Fig. 9: Reticle pod test results reproduced from [12] showing that the test reticles suffered ESD damage inside conductive plastic reticle pods when stressed by an externally generated electric field, and that the damage was made much worse by the reticle being grounded inside the pod.

An important observation relating to the results presented by Helmholz and Lering is that even though their field measuring apparatus was some of the most sensitive and temporally responsive equipment available (a picocoulomb meter connected to a fast storage oscilloscope) it did not detect the rapid field transients that the "conductive" plastic pods allowed to penetrate, and which had caused the ESD damage in their test reticles. The sensor reticle [5] used to present the field measurements previously shown also cannot accurately measure field transients with shorter duration than ~50ms, owing to the integrating electronics that the device uses.

Since a reticle can respond to (and potentially be damaged by) field changes up to GHz frequencies and beyond, such electronic sensors cannot detect all electrostatic threats that can cause damage in a reticle.

Not detecting an electrostatic threat – and even the total absence of ESD damage – does not mean that electrostatic risk is being adequately controlled, and patented "protective" solutions don't necessarily do what is claimed of them.

IV. Implications for the Electrostatic Security of Devices

The previous sections have dealt almost exclusively with the electrostatic risk to reticles, because they are the most extensively studied subjects in investigations of field induction effects in semiconductor manufacturing and they have been the primary focus of this author's work. Through the reticle studies it has been found that there are inherent weaknesses in the methods being adopted to mitigate electrostatic risk, with some ESD prevention practices creating or exacerbating other electrostatic risks that can cause damage to very sensitive items.

Technical errors have also been made in developing material handling "best practice" which, while intended to be protective, instead results in field-sensitive items such as reticles being put at an elevated risk of damage through field induction. It follows that if this undesirable situation is true for reticles, which has now been proven beyond any doubt, then it must also be true when handling other field-sensitive items in the same way. This would be especially true considering the errors that have been made in the interpretation of the risks, and the procedures that have been adopted to address them, as described earlier.

It is known that semiconductor devices are generally not as sensitive to external electric field as reticles, although some devices do exhibit sensitivity to field-induced damage under certain circumstances. For example, Wallash et al [24] report that GMR recording heads exhibit sensitivity to transient fields if one terminal of the device is connected to a short conductor that functions as an antenna. This means that components that may not be field sensitive when they are being manufactured may develop field sensitivity when they are being installed into electronic assemblies. They observe:

"the susceptibility of Class 0 devices to current transients caused by transient, high frequency fields has not been well studied. It is concluded that it is important to measure the field sensitivity of assemblies with Class 0 devices"

Sonnenfeld et al [25] in their review of failure modes in semiconductor devices also comment:

"…it is not widely known how degradation mechanisms propagate as a function of environmental conditions and various stressors. The attainment of such knowledge is critical for advancements in the field of power electronics health management and prognostics. The ability to perform large scale experiments and characterize the degradation signatures of such semiconductor devices under various scenarios is of great interest…

The assumption of new functionality will also increase the number of electronics faults with perhaps unanticipated fault modes. In addition, the move toward lead-free electronics and microelectromechanical devices (MEMS) will further result in unknown behaviors."

Both of these articles highlight the lack of knowledge about damage mechanisms and the susceptibility of advanced devices to them. They also express the view that further research into semiconductor and hybrid device damage mechanisms should be carried out. In consideration of the identified errors and misunderstandings that have been made during the development of supposedly protective handling methods used throughout the semiconductor industry, it seems prudent that field sensitivity – and the effect of exposure to electric fields during the manufacture of electrostatic-sensitive devices – should be a prominent part of such research.

It would not be wise to assume that current handling methods are safe, given the errors in them that have been identified, and especially if no research has been conducted to find out whether hitherto-undetected field-induced damage might be happening in electrostatic-sensitive electronic devices.

A flat panel display is an example of a recently-developed electronic device that exhibits extreme electrostatic sensitivity during its manufacture. The initial approach taken to try and avoid electrostatic damage was to implement the standard principles described in section III in the design of the manufacturing equipment. This did not prevent damage, which was happening as a consequence of the unavoidable charging of the panel by the manufacturing processes. It was therefore considered necessary to adopt an alternative approach, so the principles of field management rather than control of electrical potential – as described in SEMI Standard E163 – were applied.

Special coatings were developed and applied to surfaces that contact the panels so that tribocharging would be reduced; ionizers were installed to neutralize charge generated on the panels when rolling conveyors were being used; and insulating support pins rather than grounded conductive ones were employed at processing stations to prevent the concentration of any remaining electric field at the points of contact with the substrates as they were being lifted [26]. It was found that significant improvements could be made by abandoning long-established principles and taking this alternative approach to their electrostatic protection.

Re-evaluating a problem from a different perspective sometimes reveals that evidence has been misinterpreted in the past, as was found after retrospective analysis of data from the reticle damage studies that had been conducted at International Sematech [20]. This led to debate among some electrostatics practitioners about the presumed protective quality of equipotential bonding. During an online discussion initiated by this author about the possible negative consequences for device safety as a result of using equipotential bonding during handling, most contributing ESD practitioners in the discussion group stated that devices are not field-sensitive and believed that they could not be damaged in this way. Smallwood expressed doubt that concern about the use of equipotential bonding was justified, because the rationale for using it during manufacturing was sound and the results achieved by doing so were significant and positive.

However, M K Radhakrishnan, an IEEE EDS distinguished lecturer [27] commented:

"The assumption of internal damage in the semiconductor devices is correct. We have seen it in our experimental analysis studies of thin gate dielectric devices some time back. Also, we have observed that the internal electric field can cause damages not only to gate dielectric, but in many cases to other interfaces and junctions as well."

Examples of the kinds of damage that can be caused in and around electrically-overstressed device junctions can be found in Radhakrishnan's published papers, for example [28]. In this paper the authors present failure analysis results from a variety of semiconductor devices that have been damaged by ESD or by EOS, identifying through high resolution microscopy some distinguishing characteristics of the two different damage mechanisms. The paper includes TEM images of suspected ESD-induced damage to tungsten via plugs, as reproduced in Fig 10, showing progressive damage that ultimately results either in the via contact being broken (their fig. 4b) or penetrating into the silicon substrate (their figs. 4a and 9d). These images are particularly interesting because they indicate a directional quality of the damage mechanism that is similar to that seen in field-induced damage in reticles.

When chrome migration was first observed in reticles it was initially attributed to melting and reflow of the metal by the discharge current from low power ESD events [29]. This was subsequently shown to be a diagnostic error, however, after the movement of the metal was identified as field-induced migration [20], [21], [22], [23]. The directional quality of the damage mechanism in reticles and measurements of the current flowing during the damage process unambiguously

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identified that a discharge current played no part in the melting and reflow of the metal – the metal atoms moved at room temperature without any discharge occurring, driven by electric field.

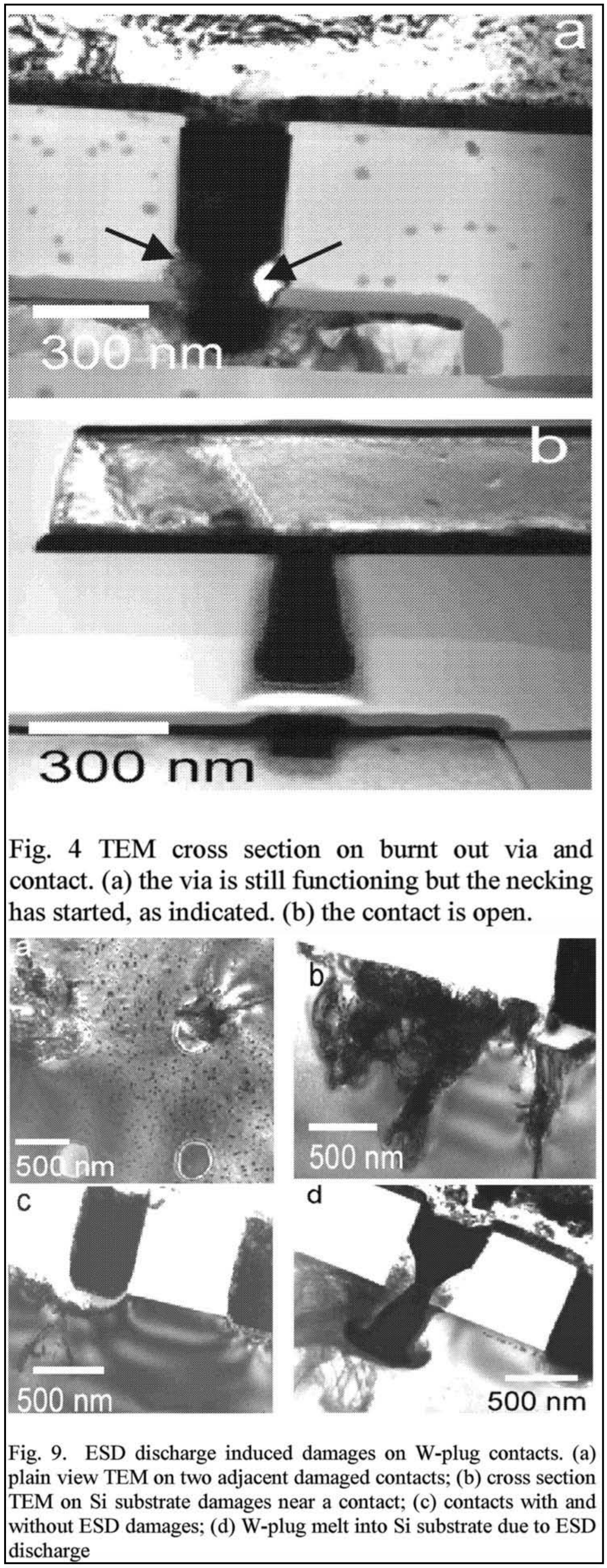

Fig. 10: TEM images of electrically damaged tungsten via plugs, reproduced from [28]

Electric field is known to enhance atomic mobility, being applied during epitaxial deposition processes to enhance the growth of crystal films [30], [31]. Sengupta and Pavlidis [30] further explain how bonding in a material can be altered by the application of an electric field.

The images reproduced in Fig 10 show a directional damage characteristic, and the region around the damage sites does not appear to have been stressed by localized heating – certainly not to a temperature sufficient to melt tungsten (>3400°C). Their images 4a and 9d show movement of the tungsten plug material into the silicon substrate, whereas their figs 4b and 9c show separation at the contact junction and no movement of the tungsten into the substrate. In their images 4a and 4b there are also discernable changes at the top of the tungsten via plugs; when the tungsten has moved towards the substrate there is a small depression visible at the top via contact, but where the tungsten has broken contact with and moved away from the substrate, there is no depression seen at the top. The contact zone within the substrate itself is also sharply defined and appears undamaged when the tungsten has moved away from the substrate (their fig 4b).

If these examples of damage had all been due to thermal overload at the interface, leading to melting of the tungsten, it is unlikely that this directional behavior would be observed, that areas in close proximity would be undamaged and that the junction would have survived to be studied by TEM. This suggests that the material movement observed in these damaged structures is possibly due to a high local electric field. Although it was observed after ESD stress testing, such damage would not necessarily be dependent on an ESD event injecting a surge of current to cause it.

Further evidence of the damaging effect of electric field within a semiconductor device is shown in Fig 11, which is reproduced from another of Radhakrishnan's papers [32]. The authors had identified that breakdown of gate oxides in FETs was often accompanied by the epitaxial growth of silicon protrusions at the site of the breakdown, a newly-identified phenomenon that they called dielectric breakdown induced epitaxy (DBIE). They attributed this epitaxial growth to the effect of a strong "electron wind" at the site of the dielectric breakdown, pushing silicon atoms either from the silicon substrate or the polysilicon gate electrode into an epitaxial hillock at the breakdown site.

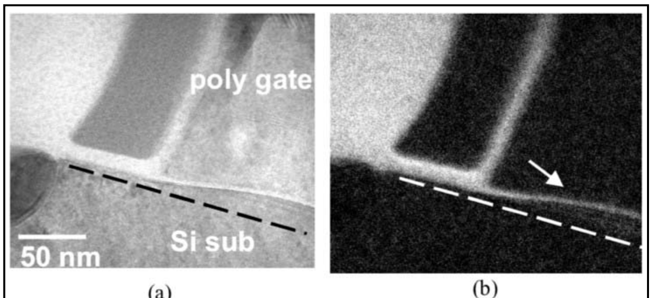

FIG. 4: TEM micrograph of a 0.18 μm nMOSFET with 33 Å Gox after a SBD for a current compliance set at 100 nA. (a) Gox was pushed up by the DBIE above the original Si substrate, as indicated by the dashed line. (b) EELS oxygen mapping showing that the gate oxide, as indicated by the arrow, was pushed-up along with the epitaxy islands.

Fig. 11: TEM image of an FET that had suffered DBIE but was still working, reproduced from [32]

However, in Fig 11 the gate oxide had not yet been ruptured by the applied stress and the transistor was still working, but DBIE was present beneath the gate oxide layer, which had bowed upwards. There is no evidence of localized breakdown of the dielectric and the DBIE is evenly distributed across the gate. On close inspection it is also possible to see faint lines beneath the distorted dielectric layer, suggesting the progressive movement of the interface through a number of discrete steps.

Rather than the epitaxial growth of the hillock being due to dielectric breakdown, a more plausible explanation for it is the field-enhanced diffusion of the oxygen atoms, followed by the re-incorporation of the silicon atoms that were left behind into a continuation of the substrate's crystal structure. It is evident from this that field-enhanced diffusion is a probable precursor to dielectric breakdown, an explanation that would be consistent with the established "percolation" models of dielectric breakdown. If this interpretation of the evidence is correct, this example indicates that the stoichiometric changes produced by electric fields within solid state devices can be somewhat more significant than previously thought – the macroscopic structure can actually move!

The online debate among ESD experts about the hypothetical enhancement of field-induced damage in semiconductor devices through the use of equipotential bonding resulted in no agreement being reached. It nevertheless generated some fresh curiosity, with Smallwood recently conducting a simple experiment to determine whether or not semiconductor devices can be damaged by field induction [33]. His experiment proved that under certain circumstances they can be damaged, without an ESD event taking place. Until this experiment was carried out to test the hypothesis, the prevailing view of ESD consultants working in the semiconductor industry has been that devices are not susceptible to field-induced damage and that grounding them is therefore both safe and protective.

That view is now shown to be open to doubt, so further investigation of field induction effects in devices and of any potential negative consequences arising from the use of equipotential bonding during their manufacture and handling would therefore be prudent.

V. Discussion

The Industry Council on ESD Target Levels white paper 2 [7] fully describes the subject and recommends a reduction in the specification for device protection. This is not, however, an indication that devices are becoming less sensitive to electrostatic damage over time, which is a conclusion that could be drawn from this recommendation. It is a response to the changing nature of CDM discharges as devices become larger and pin counts increase into the thousands. The simulated discharge current increases with package size and the smaller contacts needed to make so many connections to the device are unable to withstand the current generated by the CDM testers at the specification of 500V. It is not that the risk itself has reduced, it is that the established way of determining the susceptibility to the risk has become unsuitable. The nature of reticle electrostatic damage has also changed with shrinking feature dimensions and spacing. Retrospective interpretation of previously published data on device damage has now indicated that some of the available evidence may have been misinterpreted in the past.

Clearly, the assessment of electrostatic damage risk is something that demands constant review and revision.

Many papers have been published that have reported on the durability and performance of the various dielectrics being used for gate insulation. This is not only of interest with regard to the potential for gate oxide damage as a result of an ESD strike, but also because time dependent dielectric breakdown (TDDB) is a major cause of devices failing during use. The ability of dielectrics to work efficiently and remain durable when only nanometers thick is crucial for device scaling, which is why better performing materials are always being sought.

These studies have consistently reported that one of the main causes of dielectric failure regardless of the specific chemical composition of the dielectric is stress from an excessive electric field, which causes cumulative stoichiometric damage to the material, ultimately leading to breakdown. The evidence from TEM analysis of highly stressed FET gates indicates that field-induced structural damage may precede dielectric breakdown and device failure.

It follows from this review that there is a potential risk to all advanced devices arising from uncontrolled exposure to electric field, and even from the stresses created during normal device operation, yet this aspect of risk has not been extensively investigated, perhaps because the prevailing view among those advising the industry on electrostatic protection is that devices are not sensitive to damage by electric field.

It states in SEMI Standard E129 [2]:

"there is increasing anecdotal evidence that the presence of static charge on wafer surfaces is becoming an ESD hazard as gate oxide thicknesses become thinner. In the future, there may need to be further limits on allowable static charge on wafer surfaces to prevent ESD-related gate oxide damage during front-end semiconductor manufacturing. Further research is needed in this area."

Despite this anecdotal evidence being known about and advice for further research to be carried out being included in the SEMI Standard for two decades, little fundamental research appears to have been done in this regard, as no publications on the study of field-induced defects in devices have been identified through an online literature search. This may be due to the focus in the SEMI Standards and other static-related advisory documents being almost exclusively on ESD prevention, as the text above demonstrates by using the term "ESD-related gate oxide damage". The prevailing belief is that ESD control is already well understood and is being efficiently implemented. So unfortunately, any concern that might have arisen about this "anecdotal" dielectric damage problem would, in all probability, have resulted in ESD consultants being more stringent in the application of the standard ESD countermeasures, including the use of equipotential bonding, which probably would not have improved understanding of the situation. Dielectrics can be damaged by electric field without any ESD taking place.

As with the new reticle damage mechanisms first identified in 2003, which had incorrectly been thought to be a form of ESD damage since the cause of them is the same (exposure to electric field) [11], [29], field-induced dielectric damage in semiconductor and hybrid devices would be a cumulative process, giving no immediate indication that anything untoward had happened. Any dielectrics affected during manufacture would be unlikely to fail catastrophically when a device was tested but they could cause parametric variations in performance, and any such dielectric degradation would almost certainly contribute to early device failures through TDDB. The gate distortion seen in Fig 11 seems to support this view.

Unfortunately, if a damaged dielectric breaks down when a device is powered it is likely to result in thermal runaway that will destroy the defect site and make diagnosis of the root cause of the failure impossible. Thus, it is conceivable that a number of device failures in the field that are currently being classified as due to electrical overstress (EOS) may be caused by latent defects in the devices, resulting from dielectric damage that occurred during manufacture. It will be impossible to know whether or not this is happening without conducting more fundamental research of the kind carried out by Radhakrishnan *et al* to identify the precursor states and the factors causing them that eventually result in device failure. Investigating real-life device failures from field returns will be unlikely to produce the necessary insight because of the highly destructive nature of most final damage events.

The evidence presented here has shown that current ESD prevention practices employed in the semiconductor industry can have some negative consequences for the protection of electrostatic sensitive items. Focusing on ESD prevention alone does not guarantee adequate protection of electrostatic sensitive objects. Remaining risks have been identified that are the result of incomplete and sometimes incorrect understanding of the problems by those who have defined the "solutions". The extent of this incorrect understanding is demonstrated by semiconductor industry patents which, being based on a physical principle that has been experimentally proven to be incorrect, will actually have the opposite effect to the protective one that the designers intended. Being a prominent supplier to the industry and even being awarded a patent for an invention clearly do not guarantee that the design will actually be protective in the way the maker claims.

Reticles are extremely field-sensitive and have served as an excellent test subject with which to study electrostatic effects and field-induced damage phenomena in general. The relative simplicity of the structure of a reticle which can be easily used to perform computer simulations of field distribution and strength, the visibility of the parts that can sustain damage, the ability to perform atomic force microscopy to study the damage mechanisms in detail and then correlate their distribution with the field simulations, all without having to deconstruct the test piece, has led to new awareness about the changing nature of the electrostatic damage problem.

The characteristics of electric field behavior that have been identified through the reticle damage studies have led to the realization, as has been proven with reticles, that some handling methods being used to combat ESD in the semiconductor industry put all electrostatic-sensitive devices at heightened risk of field-induced damage during their manufacture and subsequent handling.

New generations of device are typically more susceptible to electrostatic damage effects than previous generations because device features and critical dimensions are becoming smaller over time. This characteristic is further accentuated by the changing nature of field induction with decreasing feature separation, as illustrated by the computer simulation results shown in Fig 12, which were produced to help explain the changing characteristics of field-induced damage in reticles over time. Field induction is seen to be highly non-linear and to change radically in nature as the separation of conductive features is reduced, on a dimensional scale relevant to semiconductor devices and the reticles that are used to print them.

ESD prevention methodology involves reducing the potential difference between adjacent conductive objects below the threshold for breakdown, and ESD is dependent on both voltage and separation. As the separation of conductive objects moves into the nanometer regime it becomes impossible to generate conditions that will cause ESD by field induction, because there is insufficient separation to build up a cascade of ionization (the initiation of a spark) and it is also impossible to generate a large enough potential difference. Yet, while field-induced potential differences fall rapidly with decreasing separation, the field strength produced between adjacent conductors by field induction increases exponentially.

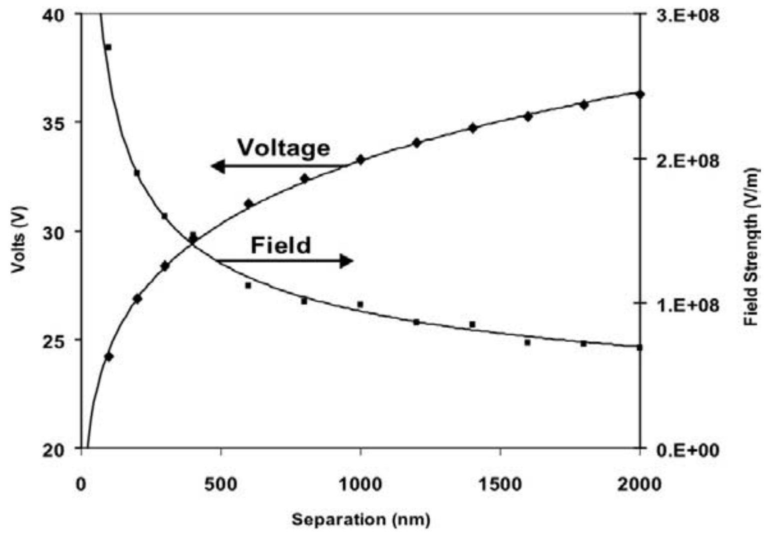

Fig. 12: Two-dimensional finite element analysis simulation of the induced potential difference and field strength between two isolated conductive lines as a function of their separation in a constant external electric field

On the dimensional scale of the features found in current production reticles, small fractions of a volt induced between adjacent conductive features can be accompanied by hazardous levels of electric field, easily exceeding ~10^6 $V.m^{-1}$ which is the measured onset threshold for EFM [22]. The features within a semiconductor device are typically 4x smaller, owing to the demagnification factor used in lithography, so this dimension-dependent field enhancement effect is even more significant, and adding dielectrics between the conductors amplifies the field strength still further. Shu et al in their report on damage to the dielectrics used in spacecraft systems [33] quantify the harmful effect of electric field thus (their emphasis):

"One major parameter is the *critical electric field for dielectric breakdown*, $E^* = 10^6$ to 10^8 V/m"

Since the physical processes that ultimately lead to dielectric breakdown are cumulative and likely to start under less extreme field conditions and to begin propagating some time before the point of full dielectric breakdown is reached (as is suggested by the TEM image in Fig 11) the field strength of concern for device safety would appear to be comparable to that which causes EFM damage in reticles. On the scale of the structures found in modern production reticles such high levels of local electric field can be produced with induced potential differences of only a fraction of a volt. Evidently devices are now being designed to operate under conditions that this analysis would suggest are capable of creating field-induced damage, so TDDB is probably inevitable. Any uncontrolled exposure to electric field would certainly not enhance their durability. Therefore, concern about any exposure of devices and the dielectric interfaces they contain to uncontrolled electric field conditions would seem to be justified.

A focus on electric field management rather than ESD prevention is perhaps more appropriate today than it was when the principles described earlier were first defined for the industry.

The complexity of electrostatics management in semiconductor production has recently risen to new heights with the introduction of EUV lithography, which is conducted in a vacuum. This complexity is admirably illustrated in the paper by van de Kerkhof [35]. Considering the advanced treatment that the subject of electrostatic control has been given in this study of the latest generation of semiconductor production equipment, it seems anomalous that decades-old and somewhat flawed approaches to electrostatic protection are still being taken with the handling of the devices that these highly advanced machines are being used to produce. As the proverb says, a chain is only as strong as its weakest link, and there are definitely some weak links that have been identified in the semiconductor device protection chain that could risk negating all the extensive effort and expense being applied elsewhere.

Attention should be drawn to the fact that the damage described as "ESD damage" to embedded structures within a semiconductor device is not itself ESD, it is a consequence of a discharge having taken place outside the device. The mechanism of the internal damage will be different from the mechanism driving the external discharge, so controlling the conditions that result in an external discharge will not necessarily eliminate all the conditions within the device that could cause internal damage. As has been observed with reticles, the application of electrostatic stress always leads to a natural relaxation that can be achieved in various different ways. If the stress relaxation does not occur via a spark or by electronic conduction, it can happen by some other means that may not be intuitively obvious. The migration of the dielectric barrier and the formation of DBIE in the FET shown in Fig 11 would not have been intuitively obvious before the advent of atomic resolution microscopy and the program of fundamental research that observed it. Such processes operating in semiconductor devices are just as likely to result in irreparable damage as they do in reticles, so more research is needed to study and characterize them.

The problem for the semiconductor industry is that it is extremely reluctant to change what is believed to be a working formula, even if problems are known about and potential improvements have been identified. If the present handling methods are deemed to be technically imperfect, but they seem to be good enough to make the devices in production today with satisfactory yield as they leave the factory, nobody seems inclined to change anything. Few managers with responsibility for assuring electrostatic compliance in a semiconductor factory would want to be the first to step out of line and adopt a different approach to that adopted by their peers, especially when so many certification schemes require the use of currently-advised practices.

Nevertheless, it cannot be a sound foundation for future device production to be using manufacturing practices that are known to be technically imperfect and to have the capability to damage sensitive devices. This is why the calls for more research to be carried out as cited and repeated here need to be heeded, so that empirical rather than anecdotal evidence as mentioned in SEMI Standard E129 can be collected, decisions about electrostatic control policies can be objectively reviewed, and if necessary they can be changed.

VI. Conclusions

The semiconductor industry is generally reactive rather than proactive. An identified problem that isn't causing losses today will often be ignored until it becomes so serious that it cannot be dismissed any longer. Unfortunately, the cost of taking this "wait and see" approach can be orders of magnitude greater than the cost of taking timely preventive action. It has been shown here that concentrating on ESD control, rather than specifically the protection of the electrostatic-sensitive devices being used and manufactured, has led to a number of technical errors and design weaknesses that ironically put those devices at elevated risk of field-induced damage.

While this situation may be survivable at present, the trend in semiconductor manufacturing as identified by industry roadmaps and Standards is inexorably towards greater susceptibility to electrostatic damage. It has been warned that unknown damage mechanisms may arise as new semiconductor device technologies and architectures are developed, and it has even been noted in SEMI Standards for decades that such damage mechanisms have been observed, but this has not yet been extensively investigated. The simple test recently conducted by Smallwood has shown that the confidence of the ESD community about devices not being susceptible to field-induced damage has been misplaced, and re-assessed evidence from past studies of semiconductor device damage have indicated that devices may not be as immune to field-induced damage as ESD experts advising the industry have hitherto believed.

It is therefore unwise for the industry to continue operating in a manner that has been identified as potentially hazardous, with technical errors embedded in operating procedures and being made in the assessment of risk, and using equipment that does not actually provide the protection that is claimed of it. A proactive approach needs to be taken to improve operating procedures, manufacturing equipment and even factory designs, and to improve the understanding of the subject by those assessing electrostatic risks and advising on best practice in semiconductor factories, so that future generations of semiconductor devices will be adequately protected against electrostatic damage. This process has already begun in flat panel display manufacturing.

A new focus on electric field management rather than ESD control is required, and research is urgently needed to quantify the susceptibility of electronic and microelectro mechanical devices to damage by exposure to electric field, both externally and internally. Until such fundamental research is done, the semiconductor industry will be in a state of "radical uncertainty" about the potential risk to devices from this cause. "Radical uncertainty" was explained as follows by Mervyn King, the former Governor of the Bank of England [36], when describing the management of economic risk. The final point he makes is perhaps the most important thing for the semiconductor industry to realize about risk assessment when knowledge is limited.

"The best example, I think is what we're going through now, COVID-19, in which we knew, well before it happened, that there could be things called pandemics. And, indeed… it was likely that we should expect to be hit by an epidemic of an infectious disease resulting from a virus that doesn't yet exist. But, the whole point of that was not to pretend that we, in any sense, could predict when it would happen, but the opposite. To say that: the fact that you knew that pandemics could occur did not mean that you could say there was a probability of 20% or 50% or any other number that there would be a virus coming out of Wuhan in China in December 2019".

"Most uncertainty is of that kind. It's where you know something, but not enough, and certainly not enough to pretend that you can quantify the probability that the event will occur."

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Abbreviations and Acronyms

CDM: Charged Device Model (of electrostatic discharge);
DBIE: Dielectric breakdown induced epitaxy;
EES: Extremely Electrostatic Sensitive (of devices);
EFM: Electric Field-induced Migration;
EMI: Electromagnetic Interference;
EOS: Electrical Overstress;
ESA: Electrostatic Attraction (of contaminants);
ESD: Electrostatic Discharge;
ESDS: ESD Sensitive;
FOUP: Front Opening Unified Pod (for handling 300mm silicon wafers);
GMR: Giant Magneto-Resistive (a type of magnetic recording head);
HBM: Human Body Model (of electrostatic discharge);
MEMS: Micro Electro Mechanical Systems;
PEEK: Poly Ether Ether Ketone;
SEMI: Semiconductor Industry consortium;
SMIF: Standard Mechanical Interface;
TDDB: Time Dependent Dielectric Breakdown.

References Références Referencias

1. SEMI Standard E78 "Guide to assess and control electrostatic discharge (ESD) and electrostatic attraction (ESA) for equipment" www.semi.org/standards
2. SEMI Standard E129 "Guide to assess and control electrostatic charge in a semiconductor manufacturing facility" www.semi.org/standards
3. Bahrenburg, F., "Challenges in achieving an ESD compliant supply chain", Dell Supply Chain ESD Audit Presentation, Oct 18, 2010
4. SEMI Standard E163 "Guide for the handling of reticles and other extremely electrostatic sensitive (EES) items within specially designated areas" www.semi.org/standards
5. Sebald, T., Rider, G., "High sensitivity electric field monitoring system for control of field- induced CD degradation in reticles (EFM)" Proceedings of SPIE Photomask and NGL Mask Technology XVI, April 10, 2009. 7379-60.
6. SEMI Standard E43 "Guide for electrostatic measurements on objects and surfaces" www.semi.org/standards
7. Industry Council on ESD Target Levels, "White Paper 2: A case for lowering component level CDM ESD specifications and requirements", www.esdindustrycouncil.org
8. Rider, G., "Protection of reticles against damage from field-induced electrostatic discharge", Semiconductor Manufacturing Magazine, September 2003.
9. Rider, G., "Reticle ESD Module 1; Electrostatic sield Simulation", SEMATECH Reticle ESD Workshop December 2003, https://www.researchgate.net/publication/327228305_Sematech_ESD_Symposium_Field_Simul ation_Presentation.
10. Bruner, J., "Design of semiconductor manufacturing equipment for electrostatic compatibility". Sematech ESD Symposium 2002.
11. Rudack, Pendley, Gagnon and Levit, "Induced ESD damage on photomasks: a reticle evaluation", Proc. 23rd SPIE Photomasks (BACUS) 2003, https://doi.org/10.1117/12.518126.
12. Helmholz, D., Lering, M., "Reticle carrier material as ESD protection", SPIE BACUS, September 2006.
13. Turley, C., Kindt, L., Kinnear, J. Jr., "Evaluating electrostatic damage prevention methods for full-scale reticle manufacturing", Proc. 35th Electrical Overstress/Electrostatic Discharge Symposium, 2013. ISBN 978-1-58537-232-4.
14. Rider, G., "Electrostatic risk to reticles in the nanolithography era", SPIE J. Micro/Nanolith. MEMS MOEMS 15(2), 023501 (2016), doi: 10.1117/1.JMM.15.2.023501.
15. Rider, G., "How to protect reticles from electrostatic damage", SPIE Digital Library, November 2018, https://spie.org/Publications/Book/2514864.
16. Levit, L., Weil, G., "Reticle boxes, ESD control and electrostatic shielding", SEMATECH ESD Impact and Control Workshop, October 20, 2001.
17. Smith, M., V., Wartenbergh, R. P., Pennybacker, W. P., "SMIF container including an electrostatic dissipative reticle support structure", Patent US6513654 B2, February 2003.
18. Li, M. C., "Electrostatic discharge-free container for insulating articles", US Patent 6,196,391 B1, March 6, 2001.
19. Cheng, D. H., Liaw, Y. H., Juang, D. G., "Electrostatic discharge-free container equipped with metal shield", US Patent 6,247,599 B1, June 19, 2001.
20. Rider, G., "EFM: A pernicious new electric field-induced damage mechanism in reticles", SEMATECH ESD Symposium Dec 2003. https://www.researchgate.net/publication/229017760_EFM-A_Pernicious_New_Electric_Field-Induced_Damage_Mechanism_in_Reticles
21. Rider, G., "Quantification of the risk of field- induced damage to reticles", SEMATECH ESD Symposium Dec 2003.
22. Rider, G., Kalkur, T., "Experimental quantification of reticle electrostatic damage below the threshold for

ESD", Proceedings of SPIE Advanced Lithography, 28 Feb 2008, Ref 6922-73.
23. Rider, G., "Electric field-induced progressive CD degradation in reticles", Proceedings of SPIE Photomasks 2008, 7122-14.
24. Wallash, A., Baril, L., Kraz, V.,Gurga, T., "Electromagnetic field-induced degradation of magnetic recording heads in a GTEM cell" IEEE EOS/ESD Symposium, September 2009.
25. Sonnenfeld G, Goebel K, Celaya J., "An agile accelerated aging, characterization and scenario simulation system for gate controlled power transistors". IEEE Autotestcon 2008.
26. Hou, C., "Flat panel display manufacturing ESD control technical fundamentals", private communication, copper_hou@leanesd.com
27. Radhakrishnan, M. K., ESD Experts discussion forum "Tribocharging and grounding - what really happens?" comment on LinkedIn. https://www.linkedin.com/feed/update/urn:li:activity:6519843348663017472
28. Tung, C. H., Cheng, C.K., Radhakrishnan, M. K., Natarajan, M. I., "Physical failure analysis to distinguish EOS and ESD failures", Proc. 9th IPFA, Singapore 2002.
29. Wiley, J., Steinman, A., "Investigating a new generation of ESD-induced reticle defects" Micro Magazine April 1999.
30. Sengupta, D., Pavlidis, D., "Control of Semiconductor Epitaxy By Application of an External Field" USAF/AFRL Research report Nov 2003.
31. Kumar, A., et al "Effect of in-situ electric field assisted growth on anti-phase boundaries in epitaxial Fe3O4 thin films on MgO" Phys. Rev. Materials 2, 054407 – 17 May 2018
32. Pey, K.L., Tung, C.H., Radhakrishnan, M.K., Tang, L.J., Lin, W.H. "Dielectric breakdown induced epitaxy in ultrathin gate oxide – A reliability concern" IEEE IEDM, 2002.
33. Smallwood, J., "Can electrostatic discharge sensitive electronic devices be damaged by electrostatic fields?" J. Phys.: Conf. Ser. 1322 012015, 2019.
34. Shu T. Lai, Cahoy, K., Lohmeyer, W., Carlton, A., Aniceto, R., Minow, J., "Deep dielectric charging and spacecraft anomalies", Ch16, Extreme Events in Geospace. https://doi.org/10.1016/B978-0-12-812700- 1.00016-9.
35. Van de Kerkhof, M., Yakunin, M., Kvon, V., Cats, S., Heijmans, L., Chaudhuri, M., Asthakov, D., "Plasma-assisted discharges and charging in EUV-induced plasma" SPIE Journal of Micro/nanopatterning, Materials and Metrology 20(1), Jan 2021.
36. Kay, J., King, M., "Radical uncertainty: decision-making for an unknowable future", London: The Bridge Street Press, 2020.

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Signal Conversion in Radio Optics of Metamaterials

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Abstract- In this paper, we propose a theory of RHM and LHM materials with the aim of their possible creation in the optical range by analogy with oscillatory processes with wave processes. The basis for signal conversion in radio optics of metamaterials is taken from radiation-induced color centers in potassium-aluminoborate glasses with paramagnetic additions of Fe^{3+} ions, interacting with color centers of the glass matrix of the 3^x and 4^x types of coordinated boron $[Bo_3]_i^{e-}$ and $[Bo_4]_i^{e+}$, respectively. A distributed parameter communication system with limited linear spatial dimensions is considered as a radio frequency analogy. In metamaterials located between the transmitter and receiver, the interaction of moving and backward waves is considered.

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Signal Conversion in Radio Optics of Metamaterials

A Salakhitdinov [α] & Kh Mirzokulov [σ]

Abstract- In this paper, we propose a theory of RHM and LHM materials with the aim of their possible creation in the optical range by analogy with oscillatory processes with wave processes. The basis for signal conversion in radio optics of metamaterials is taken from radiation-induced color centers in potassium-aluminoborate glasses with paramagnetic additions of Fe^{3+} ions, interacting with color centers of the glass matrix of the 3^x and 4^x types of coordinated boron $\left[Bo_3\right]_i^{e-}$ and $\left[Bo_4\right]_i^{e+}$, respectively. A distributed parameter communication system with limited linear spatial dimensions is considered as a radio frequency analogy. In metamaterials located between the transmitter and receiver, the interaction of moving and backward waves is considered.

I. Introduction

We have considered a method for creating a metamaterial in the radio frequency spectrum, where two parallel communication line elements are used as a cell of a metamaterial, one of which is a dielectric, the second is series-periodically connected odd single-wire open communication lines [1]. From this pair of a single element, a multilayer metastructure is created taking into account the phase of the backward waves. This method of creating Left handed materials (LHM) material [2] is broadband (non-resonant) and more versatile as applied to antenna technology than the second method of realizing a metamaterial in the form of a metastructure with a cell size much smaller than the wavelength of the transmitting signal, containing thin conducting rods and open frames [3-4].

As an example of resonator unit cells, we present the results [5-7], where a variety of cell shapes are considered in the form of broken and inserted into each other triangles, quadrangles, oval and other types, the sizes of which actually determine the narrowband characteristics, radiation pattern and gain of antennas. The external dimensions of such antenna cells reach 5-6 mm, with a gap of the order of 0.1-0.4 mm. The limited size of the unit cell does not allow mastering the creation of metamaterials in this way in the infrared (IR) and optical ranges.

Next, we will consider the possibilities of the first method [1-2] for creating metamaterials in the IR and optical ranges [8-13]. These works develop a new direction in the science of metamaterials and their applications in a wide field. This is due to the fact that Hyperboloid metamaterials make a scientific and practical contribution to optics as well as laser effects in their time. Nonlinear signal transfo-rmations using indefinite tensors $\varepsilon_{ij}(\omega)$ and $\mu_{ij}(\omega)$ [13] are practically implemented in all areas of optics: in the processes of scattering, absorption, reflection, diffraction of light, in holographic effects, wave and waveguide phenomena, in focusing light and others.

Along with hyperboloid metamaterials, an alternative direction has been developing in recent years the use of magneto-optical properties of borate glasses with paramagnetic additives ions of Cu^{1+}, Cu^{2+}, Fe^{2+}, Fe^{3+} and others [14-18]. It should be noted the features of the radiation-optical and thermo-radiation properties of potassium-aluminoborate (KAB) glasses, activated by Fe^{3+} ions, in which, on the one hand, the radiation-optical properties are well studied [18], and on the other hand, they exhibit peculiar transformations of paramagnetic radiation-induced color centers into oxygen-containing medium of the form $[BO_3]$ and $[BO_4]$, meaning 3x and 4x coordinated boron. The latter arise under the influence of X-ray and gamma irradiation of 60Co and temperature [17-18]. Radiation-induced color centers are $\left[Bo_3\right]_i^{e-}$ and $\left[Bo_4\right]_i^{e+}$ - respectively, electronic and hole color centers in borate glasses, interacting and constituting complexones of the type $\left\{\left[Bo_3\right]_i^{e-}/Fe^{3+}\right\},\left\{\left[Bo_4\right]_i^{e+}/Fe^{3+}\right\}$ and other complex ones with Cu^{1+}, Cu^{2+} ions [18].

It turned out that the simultaneous effect of the thermo radiation field causes a change in the coordination state of the activator ions in the medium in such a way that negative differential absorption $\Delta D<0$ is observed and, as a consequence, the medium becomes with a negative refractive index $\Delta n<0$ [19-20].

In this work, in contrast to [1-2], a method is proposed for studying RHM (Right handed materials) and LHM materials in order to create materials in the optical range, taking into account the analogies of oscillatory processes with wave processes [21-23]. In the calculations, we will use computer programs [24-25]. Some questions of the theory of an effective medium in metamaterials can be found in [26-29].

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II. Features of the Analogy of an Optical Wave Field with Radio Oscillations in a Communication System with Distributed Parameters

As a radio frequency analogy, let us consider an equivalent circuit of a communication system with distributed parameters [1-2] with limited linear spatial dimensions. In this case, moving and backward waves will exist in the metamaterial located between the transmitter and the receiver, similar to the phenomena in a moving wave lamp or a backward klystron used on microwave waves.

For simplicity of calculations, consider a plane scalar monochromatic wave of the form

$$E = 2A\cos\left(\omega t - kr - \varphi_0\right) = A\exp\left(i\varphi + i\omega t - ikr\right) + A\exp\left(i\varphi - i\omega t + ikr\right). \quad (1)$$

If we take both terms in expression (1), then we can consider nonlinear processes, if we take only the second term of equation (1), then we can consider linear processes. In this case, it is necessary to add a complex conjugate term. Formula (1) can be expressed as follows:

$$P = p(x,y,z)e^{-i\omega t} \quad (2)$$

Where

$$p(x,y,z) = A\exp(i\varphi)\exp\left(i\vec{k}\cdot\vec{r}\right) = |A|\exp\left(i\varphi + i\vec{k}\cdot\vec{r}\right) = |A|e^{i\phi}, \quad (3)$$

Here $|A|e^{i\phi}$ is the complex vibration amplitude.

The value k^2 is determined from the following relation

$$k^2 = 4\pi^2 \big/ x^2 = \frac{\omega^2}{c^2} = k_x^2 + k_y^2 + k_z^2, \quad (4)$$

Which determines the projection of the direction of wave propagation $k = \left(k_x, k_y, k_z\right)$.

It can be shown that in a rectangular coordinate system the components of the vector are as follows:

$$k_x = k\sin\alpha,\ k_y = k\sin\varphi\cos\alpha,\ k_z = k\cos\alpha\cos\varphi \quad (5)$$

Where the angle α is chosen between $\vec{k}$ and the plane OYZ, φ between k_z and the projection $\vec{k}$ on the plane OYZ.

It can be seen from (5) that there are only two independent angular variables:

$$k_x = u_1 = k\sin\alpha,\ k_y = u_2 = k\sin\alpha\cos\alpha. \quad 6)$$

From (4) we find

$$k_z = \pm\sqrt{k^2 - u_1^2 - u_2^2}, \quad (7)$$

hence

$$p(x,y,z) = A\exp(iy)\cdot\exp\left(\pm iz\sqrt{k^2 - u_1^2 - u_2^2}\right)\cdot\exp\left[i\left(u_1x + u_2x\right)\right]. \quad (8)$$

For the propagation of a plane wave in free space from the cutting plane of the transmitting antenna, the following condition must be met:

$$u_1^2 + u_2^2 \le k^2. \quad (9)$$

If (9) is not satisfied, then we get an inhomogeneous wave, which exponentially decays, at least along one of the coordinates k_x, k_y, k_z. Such a wave is also a solution to the wave equation.

Note that equations and expressions (5) - (9) can be used to determine the radiation pattern of the transmitting antenna in a linear approximation.

Since the electromagnetic field in the form of a plane wave (8) with different parameters is a solution to the wave equation, the solution will also be in the form of a sum (integral) of fields of the form (8) for a three-dimensional system:

$$p(x,y,z)=\frac{1}{4\pi^2}\int\limits_{-\infty}^{+\infty}\int g(u_1,u_2)e^{\pm iz\sqrt{k^2-u_1^2-u_2^2}}e^{i(u_1x+u_2y)}du_1u_2 \tag{10}$$

$g(u_1,u_2)$ where is a complex function that describes the amplitude and phase of an individual plane wave with the direction of propagation, which determines the set of real variables u_1, u_2, that is, all possible plane waves, including inhomogeneous ones.

Equation (10) is a generalization of the solution of the wave equation to the case of a nonplanar monochromatic wave, for example, for a spherical wave. From expression (10), one can pass to the real field by multiplying by *exp(-jωt)* and adding the complex conjugate term to the expression.

Let's solve the following problem: the values of the wave equation are given on the plane z=0 (the initial plane of the antenna location) of the directional pattern. It is required to find a solution of the wave equation for z≥0, which turns into a given function on the plane z=0.

From the conditions of Kirchhoff radiation on an infinite sphere of the wave field, this function should be equal to zero. From (10) we obtain the following

$$p(x,y,z=0)=\frac{1}{4\pi^2}\int\limits_{-\infty}^{+\infty}\int g(u_1,u_2)e^{i(u_1x+u_2y)}du_1u_2 \tag{11}$$

,

где

$$g(u_1,u_2)=\int\limits_{-\infty}^{+\infty}\int p(x,y,0)e^{-i(u_1x+u_2y)}dxdy \tag{12}$$

Having determined the frequency spectrum g (u_1,u_2) from (12) and p (x,y,0,t), we find the boundary conditions at z = 0.

It follows from (4.15) that for heterogeneous moving waves

$$u_1^2+u_2^2>k^2$$

and for z>0

$$p(x,y,z)=\frac{1}{4\pi^2}\int\limits_{-\infty}^{+\infty}\int g(u_1,u_2)e^{iz\sqrt{k^2-u_1^2-u_2^2}}e^{i(u_1x+u_2y)}du_1u_2 \tag{13}$$

,

For z <0, we obtain a solution corresponding to backward waves

$$p(x,y,z)=\frac{1}{4\pi^2}\int\limits_{-\infty}^{+\infty}\int g(u_1,u_2)e^{-iz\sqrt{k^2-u_1^2-u_2^2}}e^{i(u_1x+u_2y)}du_1u_2 \tag{14}$$

.

Consider special cases (13) and (14):

at z=0, y=0

$$p(x,y,0)=p(x,0)$$; (one-dimensional size, D1-case), (15)

wherein

$$g(u_1,u_2)=2\pi g(u_1)g(u_2); \quad (16)$$

$$g(\omega)=g(u)=\int_{-\infty}^{+\infty} p(x,0)e^{-i\omega x'}dx'; \quad (17)$$

$$p(x,z)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} g_1(\omega)e^{-i\omega x'}dx'. \quad (18)$$

Formula (18) is valid for any value of z. The coordinates of points in the space x, y have the dimension of length l. The variables u1, u2 have the dimension of inverse wavelength cm-1 and correspond to spatial frequencies. Formulas (13) and (14) correspond to two-dimensional (D2) Fourier integrals [30]; formulas (15-18) correspond to the usual one-dimensional (D1) Fourier integrals.

III. Calculation of the Signal Transmission System by Wave Analog for RHM Material

Consider a signal transmission system over a wave channel. For calculations, we will use formulas (15) - (18) in a simplified one-dimensional (D1) version.

Recall that to calculate the signal spectrum (17), you need to know the specific form of the input function $p(x,z_x=0)$. As mentioned earlier, as $p(x,z_x=0)$ we take the spectral dependence of KAB - glass [14-15, 18], and the shape of the absorption spectrum for a separate spectrum of the color center in the form of a Gaussian curve:

$$I_G = I^G_{0_{max}} \exp\left[-\left(\frac{\omega-\omega_0}{\Delta\omega^{\Gamma}_{1/2}}\right)^2\right], \quad (19)$$

Where $I^G_{0_{max}}$ maximum amplitude of the Gaussian curve; $\Delta\omega^G_{1/2}$ the half-width of the Gaussian is formally equal to $\Delta\omega^G_{1/2}=\frac{1}{2\sqrt{\ln 2}}\delta_{1/2}$; $\delta_{1/2}$ Gaussian curve parameter; ω_0 resonant frequency. Then formula (19) takes the following form

$$g(u)=g(\omega)=A\int_0^{+\infty} e^{-b^2x^2+2b^2xx_0}\cdot e^{-iux}dx, \quad (20)$$

Where for simplicity of calculations for the RHM material the following designations are adopted:

$$A=I^{\Gamma}_{0_{max}}\exp\left(-bx_0^2\right); \quad b=\frac{2\ln 2}{\left(\delta_{1/2}\right)^2}; \quad x_0=\omega_0; \quad x=\omega. \quad (21)$$

After transformations and calculations using the theory of residues [30], we obtain

$$g(u) = -32\pi e^{-\frac{bx_0^2}{2}} \left[e^{\frac{bu^2x^2}{2}} \cos(bx_0)ux \right] - j\left[e + 32\pi e^{-\frac{bx_0^2}{2}} \left(e^{\frac{bu^2x^2}{2}} \cos(bx_0)ux \right) \right], \quad (22)$$

$$p(u)_{RHM} = -16e^{-\frac{bx_0^2}{2}} \int_{-\infty}^{+\infty} e^{\frac{bu^2x^2}{2}} \cos bx_0 uxe^{jux} dx + \int_{-\infty}^{+\infty} e + 32\pi e^{-\frac{bx_0^2}{2}} \Big/ e^{+\frac{bx_0^2}{2}} \cos bx_0 uxe^{jux} \, du, \quad (23)$$

Here we substitute $e^{jux} = (\cos ux + j \sin ux);\ bx_0 = 1$ to simplify the solution of the problem; as a result, formula (23) is reduced to the following form

$$p(u)_{RHM} = -16e^{-\frac{x_0}{2}} \int_{-\infty}^{+\infty} \exp\frac{\tau^2}{2x_0}\cos^2\tau \frac{d\tau}{u} + j(-16e^{-\frac{x_0}{2}})e\int_{-\infty}^{+\infty} \exp\frac{\tau^2}{2x_0}\cos\tau\sin\tau\frac{d\tau}{u}, \quad (24)$$

where $\tau = ux;\ d\tau = \frac{dx}{u}.$

To determine the amount of deductions, change the following parameters $tgu = \tau;\ d\tau = \frac{2du}{1+u^2};\ \cos\tau = \frac{1-u^2}{1+u^2};\ \sin\tau = \frac{2u}{1+u^2}$. After the appropriate calculations, we arrive at the following equation

$$p(u)_{RHM} = 4\pi j + (1-j)\cdot 2^9 \pi e^{-bx_0} \varphi\left(\frac{x}{2x_0}\right), \quad (25)$$

where through $\varphi\left(\frac{x}{2x_0}\right)$ indicated $\exp\left(\frac{\tau^2}{2x_0}\right)$.

IV. Calculation of the Signal Transmission System over the Wave Channel Taking into Account the Presence of LHM Material

Calculations carried out similarly to the previous paragraph, taking into account the LHM of the material in the III-square (ε (ω) <0, μ (ω) <0), lead to the following formulas:

$$g(u)_{LHM} = -A\int_{-\infty}^{0} e^{-bx^2 - 2bx_0 x}(\cos ux - j\sin ux)\,dx \quad (26)$$

For spatial spectrum and for field distribution

$$p(u)_{LHM} = -\frac{1}{2\pi}\int_{-\infty}^{0} g(u)(\cos ux - j\sin ux)\,du, \quad (27)$$

Where the physical meaning of the variable u is reflected: on the one hand, u - has the meaning of "spatial frequencies", having the dimension of the wavelength, on the other hand, it determines the propagation of plane waves, on which we mark the extended wave field. By analogy with (23) - (26) for a medium with a metamaterial (LHM), taking into account the change of variables and the application of the theory of residues [30], we obtain:

$$g(u)_{LHM} = 16\pi e^{-\frac{bx_0^2}{2}} \left[\left(e^{-\frac{b\tau^2}{2}} \cos bx_0\tau \right) + j \left(e^{\frac{b\tau^2}{2}} \cos bx_0\tau - e^{\frac{b}{2}x_0^2 + (0.25 - x_0)} \right) \right] \quad (28)$$

from which

$$\mathrm{Re} = 16\pi e^{-\frac{bx_0^2}{2}} \left(e^{-\frac{b\tau^2}{2}} \cos bx_0\tau \right) \quad (29)$$

real part,

$$\mathrm{Im} = 16\pi e^{-\frac{bx_0^2}{2}} j \left(e^{\frac{b\tau^2}{2}} \cos bx_0\tau - e^{\frac{b}{2}x_0^2 + (0.25 - x_0)} \right) \quad (30)$$

Imagine part.

The following formulas were obtained for a metamaterial with a negative absorption coefficient:

$$p(u) = 298\varphi \left(\frac{x^2}{2x_0} \right) + j1194 \left(24\varphi \left(\frac{x^2}{2x_0} \right) - 1 \right). \quad (31)$$

V. Calculation Results and their Discussion

Using the previously obtained formulas (22), (28) - (30), we find the ratio of the spatial frequency spectra

$$\frac{|g(u)_{LHM}|}{|g(u)_{RHM}|} = \sqrt{\frac{e^{-2} + 16e^{-0,5}\varphi^2 \left(\frac{\tau^2}{2} \right) \cos^2 \tau}{1 + 8e^{-x_0}\varphi \left(\frac{\tau^2}{2x_0} \right)}} \quad (32)$$

where $\tau = ux,\ x_0 = 1$. To use a tabbed function [31]

$$\varphi_u(U) = \frac{1}{\sqrt{2\pi}} e^{-\tau^2/2}$$

transform

$$\varphi_\tau(\tau) = \sqrt{2\pi}\varphi_u(U),$$

then (32) gets the following form

$$\frac{|g(u)_{LHM}|}{|g(u)_{RHM}|} = \sqrt{\frac{0,135\varphi_u^2(\tau) + 61\cos^2 \tau}{\varphi_u^2(\tau) + 18,5}}. \quad (33)$$

Calculations by formula (33) are presented in Fig. 1.a. Figure 1 shows that in the direction of propagation of "moving waves" (u=1), a spatial spectrum is observed (Fig. 1.a) with absorption of moving waves in the frequency range $\tau=\frac{x}{x_0}=1\div 2$, while at $2<\frac{x}{x_0}<4$, there is an increase harmonics.

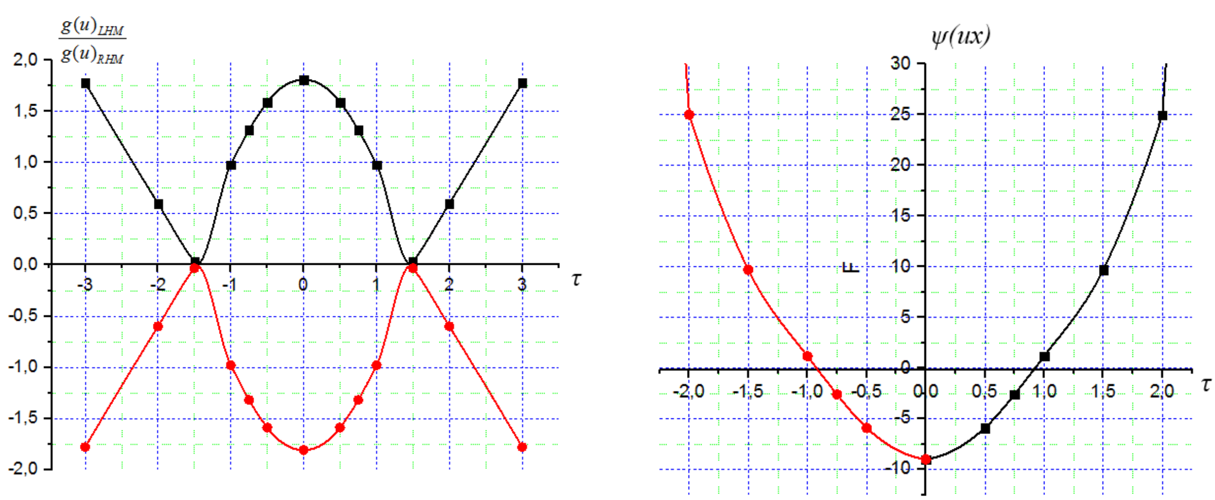
Calculations for *k=u=+1* depending on as well as for *k=+1*. This is due to the fact that in (33) φ_u^2 and $\cos^2\tau$ even functions. However, if we take into account the phase of oscillations according to (22), (26-30), then at we get

$$\psi(ux)=\frac{1}{\left[\frac{1}{4\varphi\left(\frac{\tau^2}{2}\right)\cos\tau}-\frac{1}{\pi e\cos\tau}\right]\frac{16}{e}\varphi\left(\frac{\tau^2}{2}\right)\cos\tau+e^{-\frac{1}{x_0}-(0.25-x_0)\frac{x_0}{2}}} \tag{34}$$

When *u=k=-1, x_0=1*

$$\psi(ux)=\left[\frac{1,31}{\varphi}-1,51\cos\tau\left(1+17,77\varphi_u(U)\right)\right]. \tag{35}$$

Calculations by formula (35) are presented in Fig.1.b, from the phase dependence of the spatial spectrum, it can be seen that the phase of the "moving wave" and "backward wave" changes its sign at $x/x_0\approx 1,1$.



(a) (b)

Figure 1: Frequency dependence of the amplitude (a) and phase of thespatial spectra (b)

Then let us determine the distribution of the amplitude of the electromagnetic field in a medium with a metamaterial (LHM) in relation to ordinary materials (RHM), for this we use formulas (25) and (31)

$$\frac{p(u)_{LHM}}{p(u)_{RHM}}=\frac{298\varphi\left(\frac{x^2}{2x_0}\right)+j1194\left(24\varphi\left(\frac{x^2}{2x_0}\right)-1\right)}{4\pi j+(1-j)\cdot 2^9\pi e^{-bx_0}\varphi\left(\frac{x}{2x_0}\right)}. \tag{36}$$

We transform this formula to a successful one for calculations using a tabulated function $\varphi_u(U)=\frac{1}{\sqrt{2\pi}}e^{-U^2/2}$

$$\frac{p(u)_{LHM}}{p(u)_{RHM}}=\sqrt{1+\frac{\left[300-2.506\varphi^{-1}\left(-\frac{x^2}{2}\right)\right]^2}{2.8\cdot 10^4}} \qquad (37)$$

Figure 2 shows a graph of dependence (37) depending on the relative frequency $\left(\frac{x}{x_0}\right)$, in this case, $x_0=1$ taken as a unit of measurement.

Table 1: Amplitude-frequency characteristic

$\tau=\frac{x}{x_0}$	0	0,5	0,75	1	1,5	2	3
$\frac{p(u)_{LHM}}{p(u)_{RHM}}$	3,211	3,06	3,034	2,991	2,811	2,237	2,06

For this amplitude-frequency characteristic (Table 1), broadband and amplification is manifested among metamaterials (Fig. 2).

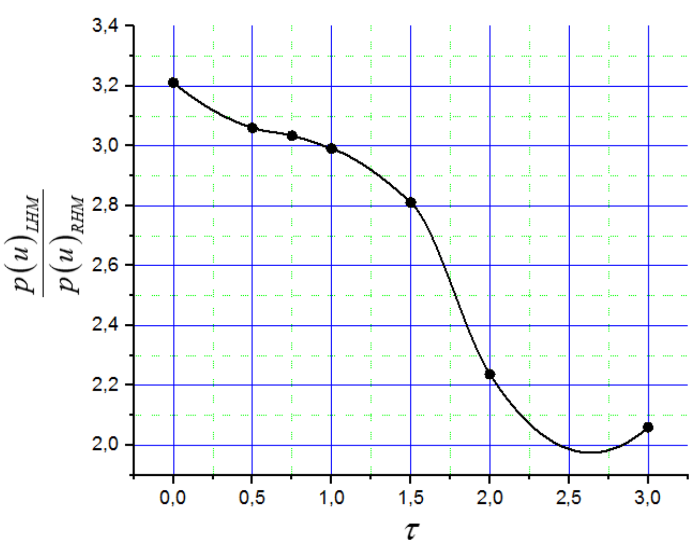


Figure 2: Distribution of the amplitude of the electromagnetic field in a medium with a metamaterial (LHM) and without a material (RHM) depending on the frequency.

VI. Conclusions

It should be noted that small gain is not a problem, since in practice, both series connected and parallel elements are created , which can provide significant gain in comparison with the considered unidirectional linear system.

Thus, the problem of obtaining a metamaterial from amorphous glass has been theoretically solved. As samples, it is necessary to take amorphous films made of magneto-optical potassium-aluminoborate glass with additions of iron oxide, which provides the necessary metamaterial parameters during radiation processing, at sufficiently high temperature irradiation.

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References Références Referencias

1. Salakhitdinov A N and Mirzokulov Kh B 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* 939.
2. Panchenko B A, Gizatulin M G Nanoantennas (English translation of Nanoantenni), Moscow: Radiotekhnika, 2010, 96 p.
3. Smith D R, Willie J P, Vier D C, Nemat-Nasser S C, Schultz S 2000 *Physical review letters* 84.
4. Shelby R A, Smith D R, Schultz S 2001 *Science* 292 5514.
5. Seleznev A D, Pachurin G V, Galka A G 2017 *International Journal of Applied and Fundamental Research* (English translation of Mezhdunarodnyy zhurnal prikladnykh i fundamental 'nykh is sledovaniy) 9.
6. Tutuncu B, Torpi H, Bulent U 2018 *Turkish Journal of Electrical Engineering & Computer Sciences* 26 3.
7. Baptiste Fix, Julien Jaeck, Patrick Bouchon, Nathalie Bardou, S. Héron, et al. High Q-factor coupled Fabry-Perot plasmonic nanoresonator. Meta-2019, Sep 2019, PARIS, France.
8. Poddubny A, Iorsh I, Belov P, Kivshar Y 2013 *Nat. Photon* 7 12.
9. Belov P A 2003 *Microwave Opt. Tech. Lett.* 37.
10. Shchelokova A V, Kapitanova P V, Belov P V 2014 *Scientific and Technical Journal of Information Technologies, Mechanics and Optics* 2 90.
11. Shalaev V M, Cai W, Chettiar U, Yuan H K, Sarychev A K, Drachev V P and Kildishev A V 2005 *Opt.Lett* 30 24.
12. Lindell I, Tretyakov S, Nikoskinen, K 2001 *Microwave Opt. Tech. Lett*. 31.
13. Smith D R and Schurig D 2003 *Phys. Rev.* 90 7
14. Kim A A, Nikonorov N V, Sidorov A I, Pixomskiy V A 2011 *Scientific and Technical Journal of Information Technologies, Mechanics and Optics* 3 73.
15. Gorbachev A D, Nikonorov N V, Stepanov S A, Nuriev A X, Shirshnev P S 2016 *Scientific and Technical Journal of Information Technologies, Mechanics and Optics* 16 1.
16. Ivanova O S, Velikanov D A, Didenko O N, Zaikovsky VI 2011 *Journal of Siberian Federal University. Mathematics & Physics* 4 4.
17. Vaxidov S A, Ikramov T I, Salakhitdinov A N 1992 *Uzbek physic journal* 3.
18. Salakhitdinov A N, Babaev A Kh, Ikramov G I, Semeshkin I V 1989 *Glass and Ceramics* (English translation of Steklo i Keramika) 46 3-4
19. Yurasov A, Yashin M, Mirzokulov Kh Ganshina E, Gramovsky A, Garshin V, Semonova D, Mirzokulov Kh 2019 *Journal of Physics: Conference series* 1389 1.
20. Yashin M, Yurasov A, Ganshina E, Garshin V, Semenova D, Mirzokulov Kh, Danilov G 2019 *Herald of the Bauman Moscow State Technical University, Series Natural Sciences* 86.
21. Gorelik G S Oscillations and waves. Introduction to Acoustics, Radiophysics and Optics (English translation of Kolebaniya i volny. Vvedeniye v akustiku, radiofiziku i optiku). Moscow: Fizmatlit, 2008, 656 p.
22. Zverev B A Radiooptics (English translation of Radiooptika). Moscow: Sovetskoe radio, 1975, 304 p.
23. Livshits M S Operators, vibrations, waves. Open systems (English translation of Operatori, kolebaniya i volni. Otkritie sistemi). Moscow, 1966, 300 p.
24. Salakhitdinov A N, Ochilov M M Certificate of official registration of a computer program, № DGU 03662, from 22.03.2016.
25. Mirzokulov Kh B, Salakhitdinov A N Certificate of official registration of a computer program, № DGU 06910, from 13.09.2019.
26. Sarychev A K, Shalaev V M Electrodynamics of Metamaterials. World Scientific publishing, 2007, 260 p.
27. Marqués R, Martín F, Sorolla M Metamaterials with Negative Parameters: Theory, Design and Microwave Applications. Wiley Press, 2008, 315 p.
28. Ziolkowski R W 2003 *Opt. Express* 11.
29. Ziolkowski R W Cheng C Y 2004 *Radio Science* 39.
30. Andre Ango Mathematics for electrical and radio engineers (English translation of Kolebaniya i volny. Vvedeniye v akustiku, radiofiziku i optiku). Moscow: Nauka, 1964, 772 p.

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Strategies for Modeling and Simulation of Alternative Energy Systems for Powering Health Facilities using HOMER Application

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GJRE-J Classification: *FOR Code: 291899*

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Strictly as per the compliance and regulations of:

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I. Introduction

Health facilities are community institutions where reliable and sustainable energy requires particular attention. Energy in health facilities is a critical enabler of access to many medical technologies, and thus to health services access. Studies conducted by World Health Organization (WHO) indicate that electricity access have a significant impact on some key health service indicators, such as: prolonging night-time service provision; attracting and retaining skilled health workers to a facility; and providing faster emergency response, including for childbirth emergencies. Without energy, many life-saving interventions cannot be undertaken (WHO, 2014).Modern energy provision is therefore a critical enabler of universal access to health care and universal health coverage.

The problems that health facilities encounter in Nigeria based on power supply are found throughout much of the world. Where there is a central power system, it is unreliable. Bringing power from the central grid to rural health facilities is not economically feasible in many cases. Hybrid systems designed with Hybrid Optimization Model for Electric Renewables (HOMER) can be cost effective and robust, solving both these issues simultaneously. Many studies throughout the world have used HOMER software to investigate the optimal design of proposed hybrid energy systems (HESs). Halabi et al. (2017), Ansong et al. (2017), Sigarchian et al. (2015), Rezzouk and Mellit (2015), and Madziga et al. (2018) used HOMER to analyze the performance of suggested HESs to find the optimal configurations. Each study proposed certain components that differed from others and the simulation was conducted for a specific area. Ani (2014) used HOMER to model energy map for off-grid health clinics in Nigeria. The author found that the most ideal solutions for the sites were hybrid systems (PV/diesel; PV/wind/diesel) with a battery backup. Malika (2016) also used HOMER to model renewable energy systems for rural health clinics in Algeria. The study focused on the optimization and the cost analysis of renewable energy hybrid systems for electricity production at rural health clinics situated in coastal, high plains and desert regions of Algeria, represented by Algiers, Ghardaia and Djanet. Regarding the cost of fuel in different regions of Algeria, the optimized renewable energy systems found for Algiers and Ghardaia are composed of PV systems, wind generators and batteries, while for Djanet it is a PV system and batteries. Ani and Emetu (2013) used the HOMER software to model robust, reliable energy systems for a rural health service facility in the southern part of Nigeria. Although HOMER is increasingly used for state-of-the-art microgrid design, these examples go back to HOMER's roots as a tool for electrification. The benefits of electrifying rural health clinics can literally mean the difference between the health clinics standards of the "dark ages" compared to that of the modern world. By having electricity, a health clinic will have prolonged opening hours. With more electricity, health clinics could access basic medical devices and appliances, such as vaccine refrigerators, as well as general equipment such as water sterilization, heating, cooling, and ventilation.

An international donor agency United States Agency for International Development (USAID) (2016)has been working with a health clinic in the Kalahari Desert of Botswana to improve local health care service delivery. The health clinic is not connected to the grid and currently utilizes a diesel generator to partially meet its energy needs. The donor agency

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decided to explore different options for upgrading the clinic's power generation systems, by comparing costs for a variety of different energy generation systems that can meet 100% of the clinic's load using HOMER program. Evaluating the energy generation options, the resulting cost estimates show that the lowest cost system is a PV/diesel-battery hybrid system. A diesel-battery system costs 13% more than this hybrid system because the added fuel cost over the life of the system is more than the savings in initial PV investment, and a PV-battery system costs about 28% more than the least-cost design. In diesel only system, the cost of energy from a diesel system with no batteries is over twice the cost from a diesel-battery system. The calculations demonstrate that because of fuel and maintenance costs, the system with the lowest capital cost is not the system with the lowest lifetime cost of energy.

World health organization (2016) conducted a simulation to compare the costs of different stand-alone power supply technologies to a hypothetical health clinic in rural Kenya, using HOMER Power System Design tool. The simulation tested and compared power supply arrays reliant upon a fuel-based generator, PV and generator combinations, and PV only, with and without battery backup; and looked at costs of the different supply options (both initial and long-term), as well as the pollution and climate emissions. The simulation further explored these supply options for two demand scenarios: one using conventional medical devices and one using more energy-efficient medical devices that reduce the clinic's overall energy demand. The simulation provides an interesting example of how optimal combinations of photovoltaic and diesel generation with appropriate energy storage can yield multiple gains: lower overall cost of energy, a shift to renewable energy, and a reliable supply for all health facility energy needs. The simulation also demonstrates how investments in more energy-efficient medical devices, can help reduce the required capital investment in energy supply for a rural health clinic. The results of the simulation demonstrate that the best combination remains energy efficiencies + more efficient supply configurations.

a) Description of HOMER Software

HOMER is a computer model developed by the United States (U.S.) National Renewable Energy Laboratory (NREL) to assist in the design of power systems; evaluate technical (power system's physical behavior) and financial (power system's life-cycle cost, which is the total cost of installing and operating the system over its life span) options for on-grid and off-grid power systems, for distributed generation and stand-alone applications. This software application (HOMER) helps to facilitate the comparison of power generation technologies across a wide range of applications. It allows one to model the performance of a power system configuration and determine its technical feasibility and life-cycle cost; compare many different design options based on the satisfied technical constraints at the lowest life-cycle cost; and assists in understanding and quantifying the effects of uncertainty or changes in the inputs. In 1993, NREL developed the first version of HOMER for the U.S. Department of Energy (DOE) for renewable energy programs. The developed design tool (HOMER) was used in predicting the long-term performance of hybrid power systems and to understand the tradeoffs between different energy production configurations. HOMER has a user-friendly windows-based interface with a library of input data files and users can readily model new applications. HOMER simulate different system configurations, or combinations of components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. It displays simulation results in a wide variety of tables and graphs that help one compare configurations and evaluate them on their economic and technical merits (Getting Started Guide, 2005).

b) Literature Review

Based on literature search, many case studies concentrate on the use of HOMER at the national, regional, and rural communities for households scale (Olubayo et al., 2019; Shahinzadeh et al., 2016; Cristian et al., 2017; Budes et al., 2020; Acakpovi et al., 2015; Razmjoo and Davarpanah, 2018; Farid et al., 2017; Nagger et al., 2018; Bahramara et al., 2016; Adetunji et al., 2018; Al-Hamdani et al., 2016; Hassan et al., 2016; Rajbongshi et al., 2017; Ronad and Jangamshetti, 2015; Jamalaiah et al., 2017; Rohit and Subhes, 2014; Deshmukha and Singha, 2019; Al Garni et al., 2018; Zahboune et al., 2016; Mohammed et al., 2013; Shahinzadeh et al., 2015a; Shahinzadeh et al., 2015b) with only a few research efforts directed at healthcare facilities. Furthermore, the strategies for modelling and simulation of alternative energy systems for powering health facilities have not been comprehensively studied. Razmjoo and Davarpanah (2018) studied four different models of hybrid renewable energy systems with a combination of photovoltaic panels, wind turbine, and diesel generators for residential application in Damghan city. Simulation, optimization, and modeling procedures were done by HOMER software. The simulation results show that among three hybrid systems investigated, PV-wind system has the highest value of electrical production with 18,478 kWh/yr and the PV-diesel system has the lowest value of electrical production with 9,876 kWh/yr. Moreover, from the environmental view, the PV-Diesel system is highest with2,402 kg/yr and the PV-wind system has the lowest pollution rate, i.e., 0%.Shezan et al (2016) carried out a research to analyze the performance of an off-grid PV (photovoltaic)-wind-diesel-battery hybrid energy system for a remote area located in the state of Selangor, Malaysia. The system was designed as well as simulated to support a small community considering an average load demand of 33 kWh/day with a peak load of 3.9 kW. The simulation and optimization of operations of the system was done by HOMER application using the real time field data of solar radiation and wind speed of that area. The simulation ensures that the system is suitably feasible with respect to net present cost (NPC) and carbon dioxide (CO2) emission reduction purpose. The result shows that NPC and CO2emission can be reduced about 29.65% and 16 tons per year respectively compared to the conventional power plants. The NPC of the optimized system has been found about USD 288,194.00 having the per unit Cost of Energy (COE) about USD 1.877/kWh. The analyzed hybrid energy system might be applicable for other region of the world where the climate conditions are similar. Similar research was conducted in Shezan and Ping (2017) which uses the HOMER to design an off-grid Hybrid PV-Wind-Biomass-Diesel Energy Systemin order to support a small community having an average load demand of 80kWh/d with a peak load of 8.1 kW. The simulation ensures that the system is economically and environmentally feasible with respect to NPC and CO2 emission limitations. The result shows that the NPC of the optimized system has been found to be about USD 160,626.00, having the per unit COE of USD 0.431/kWh. In a related research, a PV–wind–diesel system was designed by Bernal-Agustín et al. (2006) to minimize the total cost of system installation and to reduce the pollutant emissions by using HOMER software. The results demonstrated the practical utilization of the method used. Bekelea and Boneya (2011) designed a wind-PV hybrid power system for supplying electricity for a community living in Ethiopian remote area using HOMER. Moreover Kusakana and Vermaak (2013) used HOMER to investigate the possibility of using hybrid PV–wind renewable systems to supply mobile telephone stations in remote areas of Congo. Li et al. (2013) presented a techno-economic feasibility study of an autonomous hybrid wind/PV/battery power system for a household in Urumqi, China using Hybrid Optimization Model for Electric Renewable (HOMER) simulation software. They recommended a hybridwind/PV/battery system with 5 kW of PV arrays (72% solar energy penetration), with a one wind turbine of 2.5 kW (28% wind energy penetration), 8 unit batteries each of6.94 kWh and 5 kW sized power converters for the household. Furthermore Ngan and Tan (2012) analyzed the implementation of hybrid photovoltaic (PV)/wind turbine/diesel system in JohorBahru, Malaysia and used “HOMER” software. Bad awe et al. (2012) integrated and optimized a hybrid wind and solar energy system to an existing diesel generator with a battery backup to supply power to telecommunication towers using HOMER software. Their results indicated that the hybrid renewable energy system is a cost effective solution.

HOMER software is one of the tools being used by WHO for designing renewable energy health facilities. HOMER can evaluate a range of equipment options over varying constraints to optimize small power systems for health facilities. HOMER’s flexibility makes it useful in the evaluation of design issues in the planning and early decision-making phase of health facility electrification projects. Therefore, the aim of this paper is to design energy system options that can optimize health services delivery, using HOMER software and demonstrates in detail the depth of the software application; teach health workers step by step on how to model renewable energy health facilities. The objective of this research is to ensure the uninterrupted power supply to the health facilities in the remote and decentralized areas, to ensure environmentally safe energy system, to reduceCO2 and other greenhouse gas (GHG) emissions, to reduce the COE and improving the NPC.

II. Methods and Materials

a) Modeling of Alternative Energy System Components

Before going to the computer simulation, modeling of alternative energy system components is done step by step as described below. The proposed system contains wind energy sub-system, PV sub-system, diesel generators unit and battery storage sub-system.

Step One: Defining the Power System

This schematic (Add/Remove Equipment to Consider) shown in Figure 1 represents all of the technology options for a power system design. The power system design can be defined by clicking the Add/Remove button. For this exercise, we selected a number of different components as shown in Figure 1 by clicking the check box of each of the following: Primary Load 1 (Health Facility Load), PV, Wind Turbine 1 (BWC Excel-R), Converter, Generator 1 (diesel generator) and Battery 1 (Surrette 6CS25P). At the bottom of the window select ‘do Not Model Grid’, and Click OK to return to the Main window.

Step Two: Defining the Facility Load and its Location

The load inputs describe the electrical demand that the power system must be served according to a particular schedule. In this case, clinic personnel must examine their facility’s specific needs and discuss them with energy design experts. The needs assessment will include an inventory of the types of equipment used in the facility, the power required to operate each device, and the average “daily load”, or the amount of power required to operate equipment under normal working conditions. Therefore, in this study, the hourly load profile of each load [shown in Table A1 of the supplementary data] needs to be entered into primary load according to the setup defined in the schematic and model. To find wattage information for a given

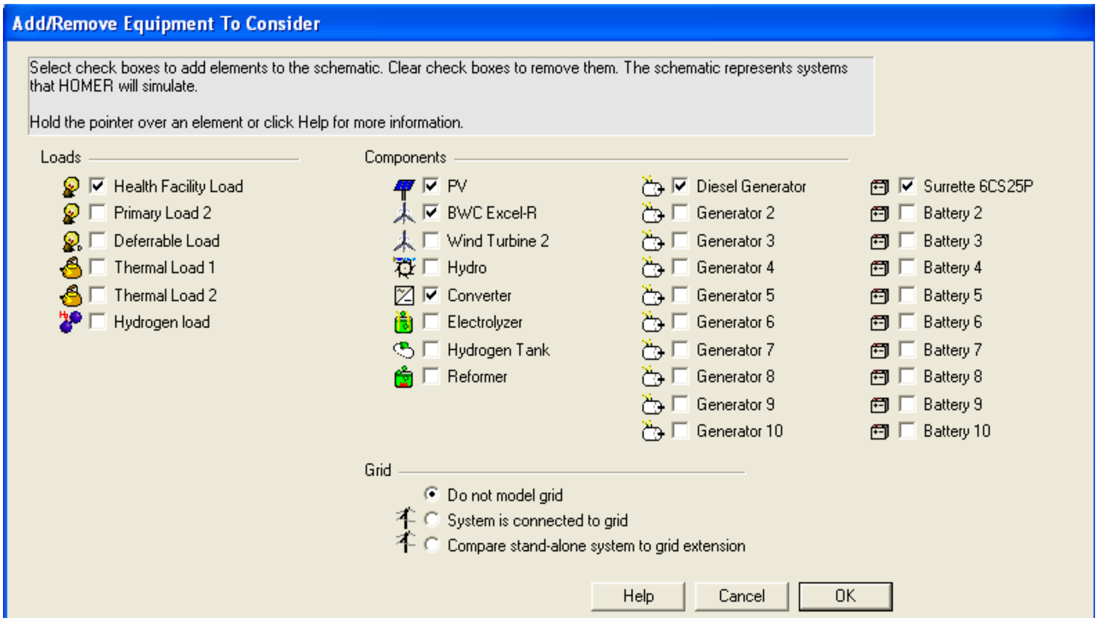


Figure 1: Add/Remove window of different components

device, check the user's manual or it may be written on the back of the device. A Health facility load profile depends on multiple parameters including lighting for child delivery and emergency night-time care, refrigeration for blood and vaccines, sterilization facilities, electricity for simple medical devices, etc., and for this reason, it is important to outline an accurate power profile in order to dimension correctly the renewable components for the facility. The adoption of energy efficiency can reduce energy consumption and increase renewable energy penetration (Babatunde et al., 2019; Olubayo et al., 2019). It can also reduce cost of energy and emissions. The simulation concerns a standard health facility described by (Ani and Emetu, 2013). Obviously, many rural health clinics in Nigeria have the same electrical load data with that of Ani and Emetu (2013) which can be used in the establishment of a general case study for the electrical load data; therefore it was used by Ani (2014)to study three hypothetical off-grid remote health clinics at various geographical locations in Nigeria; which will be use here as an example to the study. The electrical load (Power supply requirements) data for a Health facility is shown in Table A1 of the supplementary data, which was used to define the hourly profile, and the random variability parameters was set to 0% for accurate power load measurements as indicated in Figure 2.

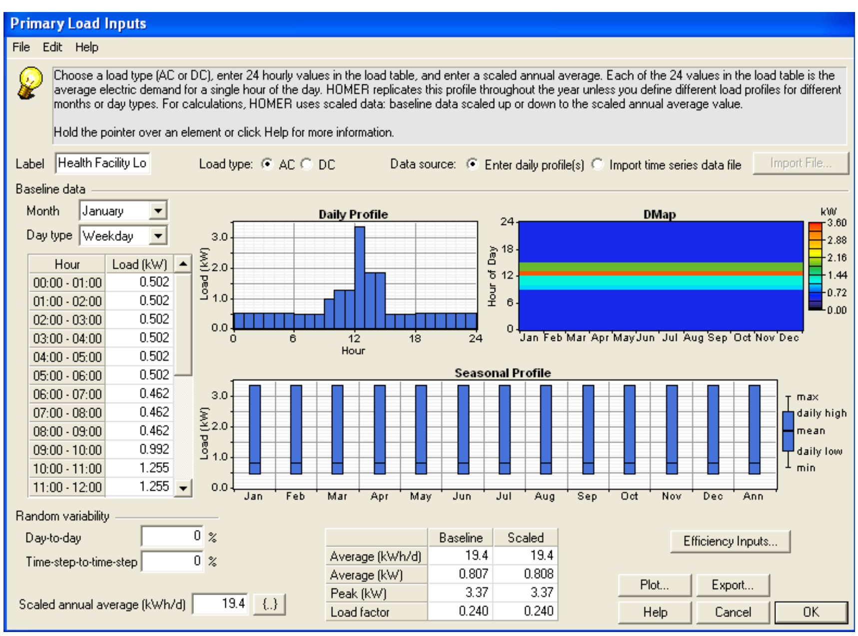


Figure 2: HOMER output for the Primary load

Strategic Thinking and Adjusting for Change

Once a facility has comprehensively analyzed the energy requirements of its daily operations, it must be determined whether those demands are likely to change. One must think strategically about the possibility that energy demands may increase due to the addition of new services or extended operating hours.

b) Power Generation Options

After determining the facility's typical daily energy usage as described above, it is time to evaluate the energy technologies available to electrify the facility. Rural health clinics have a number of options available to supply reliable electricity. The best option for a given application depends on energy technology drivers such as the capital cost, operating cost, reliability, and durability.

Capital Cost is the initial cost to purchase and install the equipment. Power equipment – including generators (PV panels, wind turbine, and diesel), inverters, charge controllers, and batteries – can vary greatly in cost and quality. In many cases, higher-quality models will cost more, but can have a greater return on investment in terms of greater reliability of power and longer system lifetimes. Costs also vary considerably based on the local market.

Operating Cost includes the cost of fuel (where applicable), operations and maintenance, and parts purchased for repairs. Operating costs will vary more than capital costs, due to differences in:

- Fuel prices over time and from location-to-location.
- Use patterns - systems will experience more or less stress in a given day, based on the number of hours they operate, the amount of power they provide, and the type of equipment drawing loads (e.g., high intensity equipment such as sterilizer oven (laboratory autoclave), as opposed to low-intensity equipment such as lighting); and
- Environmental conditions.

Reliability is expressed as a fraction of time the equipment is available to provide power. Generators need to be taken off-line for service periodically; wind and solar power systems require optimal weather conditions to operate at maximum efficiency. Systems can generally achieve greater reliability by adding backup components; hybrid systems (include photovoltaic panels and/or a wind turbine, batteries, and a generator) which has the ability for one system to support the other provide greater flexibility, although this generally increases cost and complexity.

Durability is the typical system lifetime, expressed either in years or in hours of run-time (for engine generators).

Facility Location - The Case Study Sets of Locations in Nigeria

The locations of the hypothetical health facility are chosen to reflect the various geographical and climatic conditions in Nigeria. Nigeria is divided into three main climatic regions: the equatorial climatic region where the global solar radiation ranges from 4.1 to 4.9 kWh/m^2/day, the tropical climatic region where the global solar energy is around 5kWh/m^2/day, and finally the arid climatic region where the global solar radiation is higher than 5kWh/m^2/day, while the wind is characterized by a moderate speed (2.4 to 5.4m/s) as can be seen in (Ani, 2014). These locations for the hypothetical health facility are: Nembe (Bayelsa State) in the equatorial climatic region, Abaji (Abuja, FCT) in the tropical climatic region, and Guzamala (Borno State) in the arid climatic region.

Step Three: Renewable Energy (Wind and Solar) Resources

The availability of renewable energy system (RES) at a location differs considerably from location to location. This is a vital aspect in the development of the power system. The performances of solar and wind energy components are influenced by the geographical location and climatic conditions. As RES (solar and wind) are naturally available and intermittent, they are the best option to be combined into a hybridized diesel system. These resources (solar and wind) depend on different factors such as the amount of solar energy available is dependent on climate and latitude (your specific location on the Earth's surface), the wind resource is influenced by atmospheric circulation patterns and geographic aspects; in turn influences when and how much power can be generated. The specific geographical locations (latitude and longitude) of the health facility based on solar and wind resources are discussed below.

c) Wind Resources

Wind resources can be determined by using the National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy database. Therefore, to determine the wind resources of a location, log into the NASA Meteorology website (http://eosweb.larc.nasa.gov/) and enter the coordinates and select the annual wind speed average, which (the annual wind speed average) is a good indicator of the suitability of the installation of a wind turbine in any given location. Generally, values above 7m/s with few months below 5m/s are considered adequate for satisfactory results (Kassam, 2011). Once the data is received, click on the wind resource icon in HOMER and click on the "enter monthly averages" and enter the monthly wind data, then fill the Altitude and Anemometer Height with the appropriate information. For this exercise, a hypothetical site coordinates of 4° 17' N latitude and 6° 25' E longitude for Nembe (Bayelsa State), of 9° 00' N latitude and 7° 00' E longitude for Abaji (Abuja, FCT), and latitude 11° 05' N, longitude 13° 00' E for Guzamala (Borno State), were used as indicated in Figure 3.

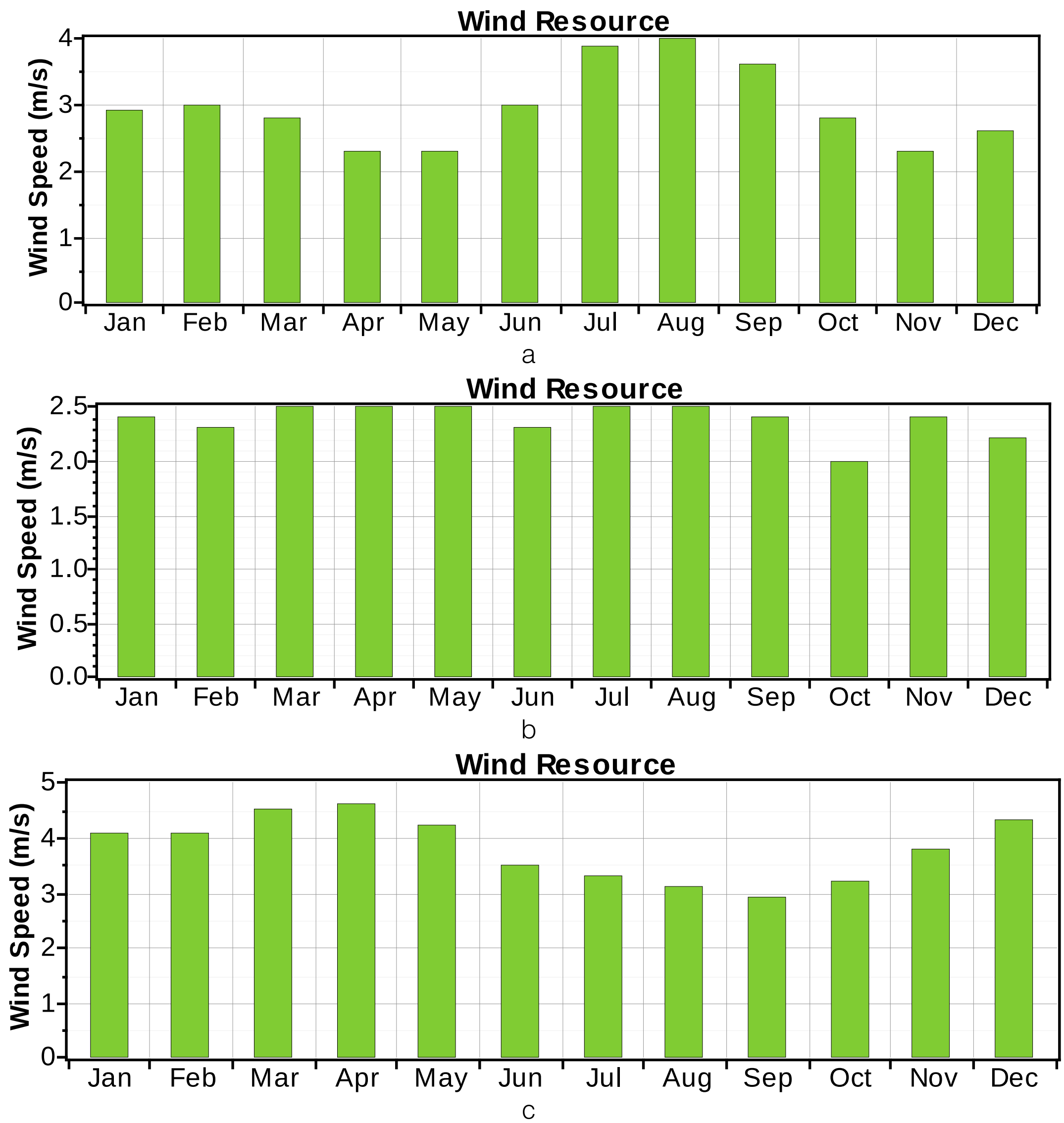
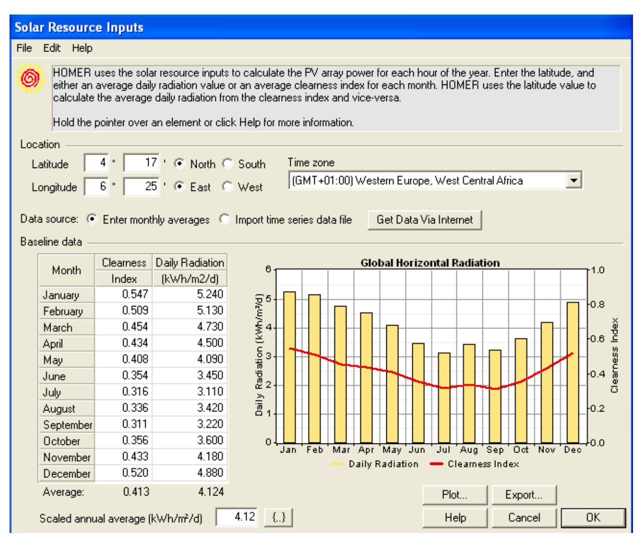


Figure 3: HOMER output graphic for wind speed profile in (a) Nembe, (b) Abaji, and (c) Guzamala

d) Solar Resource

Solar resources can be obtained directly via internet by HOMER from the NASA Surface Meteorology and Solar Energy database by entering the GPS coordinates. NASA provides extensive information on solar resources by month for any location in the world (http://eosweb.larc.nasa.gov/sse/). Using the coordinates from the wind resources above, the annual solar radiation of these areas are4.12kWh/m²/d for Nembe (Bayelsa State), 5.45 kWh/m²/d for Abaji (Abuja, FCT), and 5.90 kWh/m²/d for Guzamala (Borno State) which can be seen from Figure 4. Kassam (2011) advised that the average radiation should have a constant trend and that the annual radiation should be above 5kWh/m²/d in order to have a reliable source of power coming from the photovoltaic panels.



a

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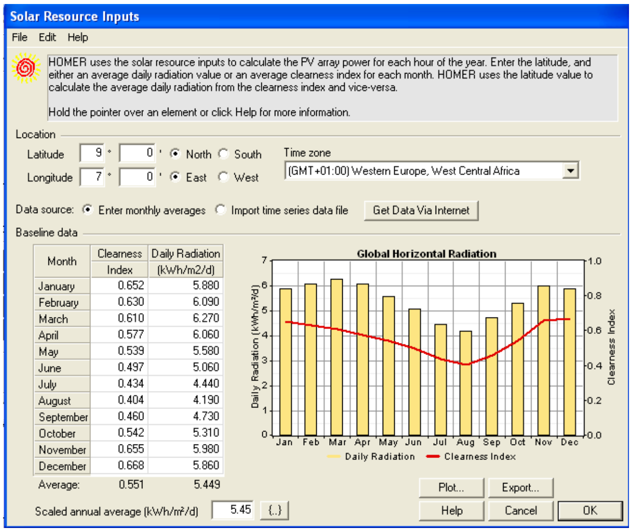

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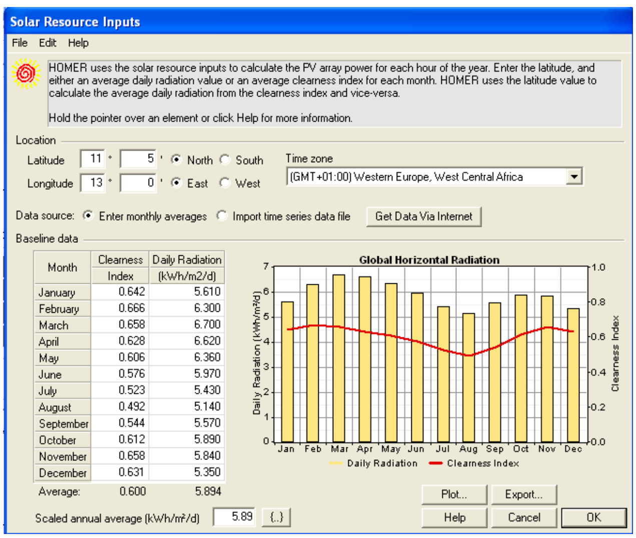
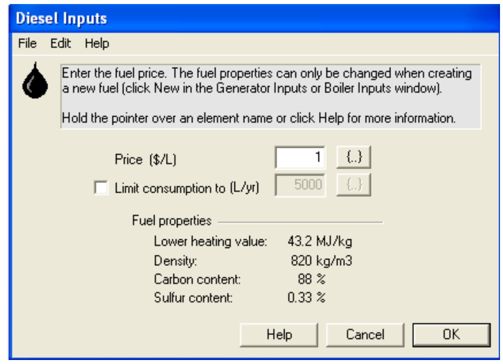


c

Figure 4: HOMER output graphic for Solar (clearness index and daily radiation) profile in (a) Nembe, (b) Abaji, and (c) Guzamala

Step Four: Diesel Price

Diesel price has a significant impact on the running costs of a system equipped with a diesel generator (Kassam, 2011).The diesel price can be added by clicking the diesel icon in HOMER, then click on the "Diesel Inputs" and enter the diesel price.In the exercise,1$US/L for Nembe, 1.5$US/L for Abaji and 1.8$US/L for Guzamala, were considered as reference price for the diesel as shown in Figure 5.



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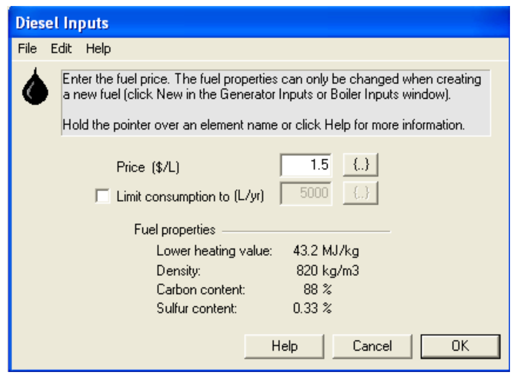

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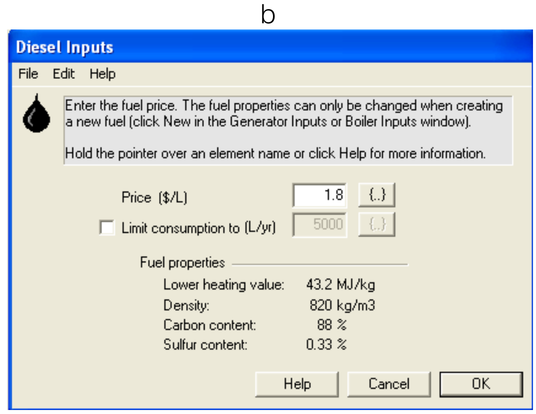


c

Figure 5: HOMER input for diesel price profile in (a) Nembe, (b) Abaji, and (c) Guzamala

Step Five: Economics

The economic factors of the project shown in Figure 6 can all be defined by clicking on the Economics icon in HOMER .In this exercise, a real annual interest rate of 6% was assumed. The real interest rate is equal to the nominal interest rate minus the inflation rate. The appropriate value for this variable depends on current macroeconomic conditions, the financial strength of the implementing entity, and concessional financing or other policy incentives. Also, the project lifetime was set to 20 years – inline with the expected life span of the renewable equipment (wind turbine, photovoltaic system). Diesel generators and batteries have usually a much lower lifetime, which largely depends on the conditions where the equipment operates and the maintenance performed (Kassam, 2011).

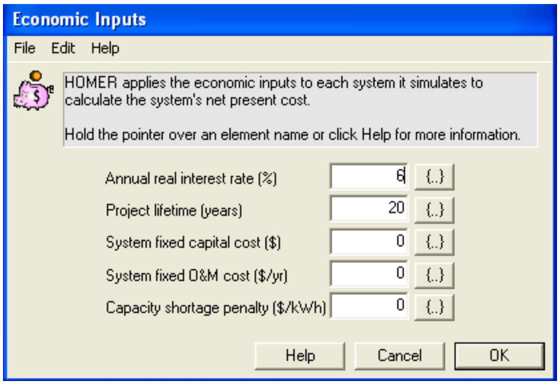


Figure 6: HOMER input for economics

Step Six: Equipment

Diesel Generator

The Generator in the power system can be defined by considering the Size, Cost, Replacement Cost, Operating Lifetime, and Operations & Maintenance (O & M) expenditure of the generator. In generator-only systems, the generator must be sized to handle the peak expected load, but the system frequently runs at lower loads at reduced efficiency. Therefore, in such situation, a battery bank can be added to a generator-based system to reduce run time and save fuel costs. The addition of batteries to a diesel system are often a good investment in terms of fuel savings.

In this exercise, by clicking on the Generator icon, a2.5kVA diesel generator has been considered. The minimum allowable load on the generator has been set as 30% of its rated capacity and has 20,000 operating hours life time. The default efficiency curve present in HOMER was used, as often vendors do not provide comprehensive details to design a specific efficiency curve. Generators typically have low capital cost compared to other alternatives, but higher operating costs due to the need for fuel(USAID, 2016). Initial capital cost will vary with the size and type of generator, while the Operating costs will vary depending on the level of usage. Generators have several maintenance requirements; and maintenance checks will vary depending on the design of the engine and its duty cycle (whether it is a primary energy source or a back-up/emergency unit). Engine oil and the oil filter should be changed after approximately 1,000 hours of operation. Meanwhile, it is often difficult to determine the generator hourly maintenance cost (the expense and transport associated with acquiring diesel) due to many health facilities have contract with companies or individuals to supply diesel to the generator at the facility and also manage the generator's O&M services. In the exercise, an hourly O&M cost of 0.1 US$ were assumed as indicated in Figure 7.

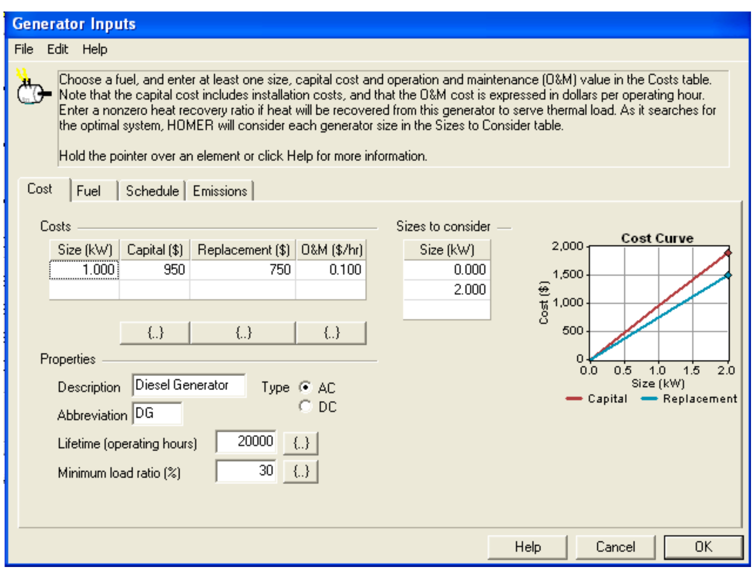


Figure 7: HOMER input for fuel generator

e) *Mathematical Model of Diesel Generator*

Hourly energy generated by diesel generator (E_{DEG}) with rated power output (P_{DEG}) is defined by the following expression (Deepak et al, 2011):

$$E_{DEG}(t) = P_{DEG}(t) \times \eta_{DEG} \text{ ---------------------------------(1)}$$

For better performance and higher efficiency the diesel generator will always operate between 80 and 100% of their kW rating, where η_{DEG} is the diesel generator efficiency.

f) *Converter*

Converter in the power system represents both an inverter (for the conversion of generated direct current (DC) power into required alternating current (AC) power; both for energy flowing directly to the load from the PV and for energy transiting through the battery), and a rectifier (for the conversion of generated AC power in order to charge the battery).It is a device that can convert electrical power from ac to dc in a process called rectification and from dc toac in a process called inversion (Shezan et al., 2016). When defining the converter, the key parameters to consider are the energy conversion efficiencies, Size, Cost, and O&M Cost as shown in Figure 8.

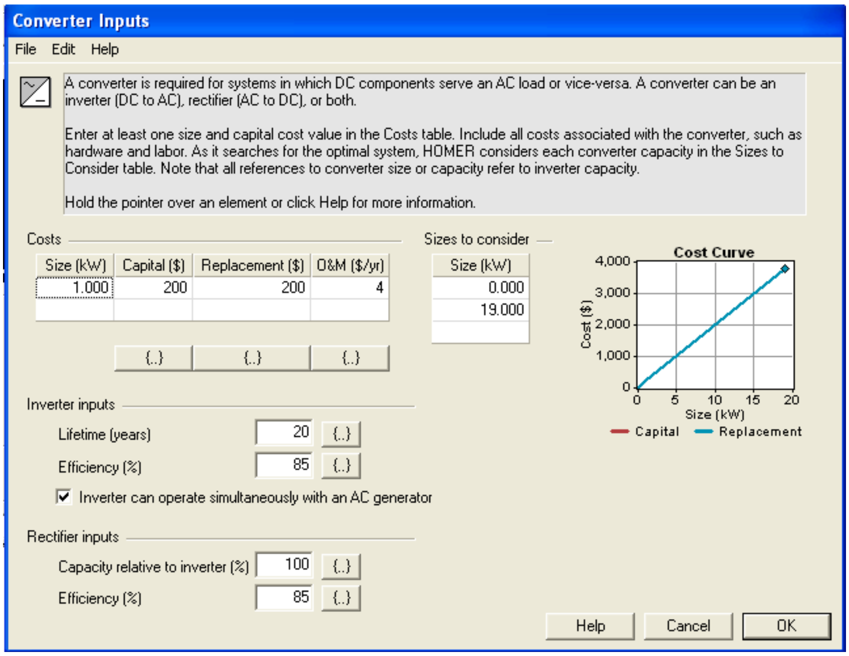


Figure 8: HOMER input for converter

g) Mathematical Model of Converter

In the proposed scheme converter contains both rectifier and inverter. PV, wind energy generator and battery sub-systems are connected with DC bus while diesel generating unit sub-system is connected with AC bus. The electric loads connected in this scheme are DC loads (Ani, 2015).

The rectifier is used to transform the surplus AC power from the diesel electric generator to DC power of constant voltage. The diesel electric generator will be powering the load and at the same time charging the battery. The rectifier model is given below(Ani, 2015):

$$E_{REC-OUT}(t) = E_{REC-IN}(t) \times \eta_{REC} \text{ ------------------------(2)}$$

$$E_{REC-IN}(t) = E_{SUR-AC}(t) \text{ ---------------------------------(3)}$$

At any time t,

$$E_{SUR-AC}(t) = E_{DEG}(t) - E_{Load}(t) \text{ -----------------------(4),}$$

where $E_{REC-OUT}(t)$ is the hourly energy output from rectifier, kWh, $E_{REC-IN}(t)$ is the hourly energy input to rectifier, kWh, η_{REC} is the efficiency of rectifier, $E_{SUR-AC}(t)$ is the amount of surplus energy from AC sources, kWh, $E_{DEG}(t)$ is the hourly energy generated by diesel generator.

h) Storage System - Battery

Battery is a device that stores energy and makes it available in an electrical form. Batteries are not a power technology, but a means of storing the power produced by other systems, such as photovoltaic and/or wind systems, hybrid systems. The battery stores the generated electricity during the availability of the renewable energy sources and the stored energy supplied to the consumer whenever required (Partha and Nitai, 2020). For some renewable energy clinics, batteries can be used to provide backup power during surges and outages. However, if renewable energy is absent for a lengthy period of time, some other system (generator) would be useful to recharge the batteries. Batteries' lifetimes are partly dependent on the cycling (charging and discharging) they experience. HOMER provides a library of several predefined batteries, and users can add to the library if necessary. When choosing from the library, the key parameters to consider or include are the Nominal Capacity, Voltage, Round Trip Efficiency, Minimum State of Charge, Capacity Curve and Lifetime Curve (User Manual, 2016). By clicking on the battery icon (selected or created) in HOMER we are able to define the battery bank used in the power system by entering the cost of the battery, the number of batteries per string and the number of strings of batteries. Therefore, in this exercise, a single string of Surrette 6CS25P battery, 6V/1,156Ah sealed lead-acid batteries were considered as indicated in Figure 9.

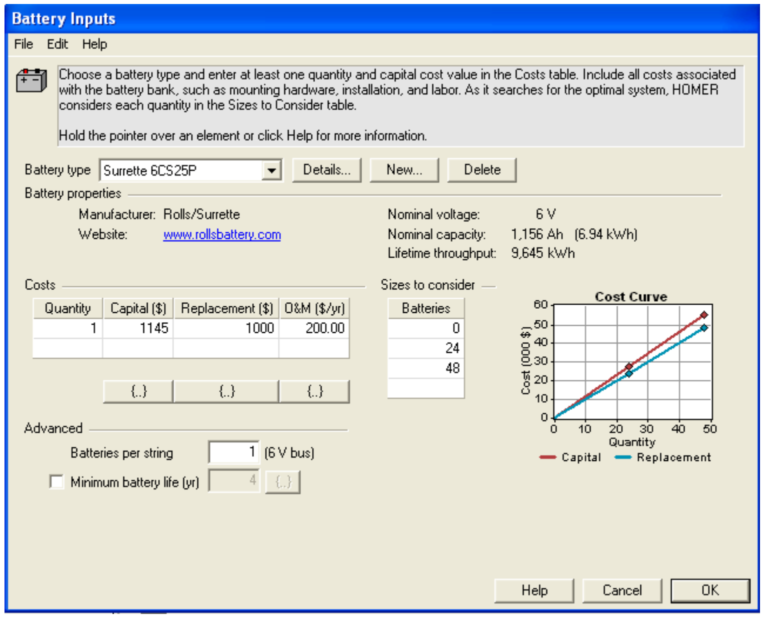


Figure 9: HOMER input for storage battery

i) Mathematical Model of Storage Battery

HOMER uses the Kinetic Battery Model (Manwell and McGowan, 1993) to determine the amount of energy that can be absorbed by or withdrawn from the battery bank each time step. HOMER determines the total amount of energy stored in the battery at any time as the sum of the available (energy that is readily available for conversion to DC electricity) and bound energy (energy that is chemically bound and therefore not immediately available for withdrawal) by the following equation(HOMER help, 2015;User Manual, 2016):

$$Q = Q_1 + Q_2 \text{ --(5),}$$

where:

Q_1 is the energy in kWh that is readily available for conversion to DC electricity.

Q_2 is the energy in kWh that is chemically bound and therefore not immediately available for withdrawal.

Each hour of the simulation, the maximum amount of power that the battery bank can withdraw (or absorb) is being calculated using maximum discharge (or charge) power. The maximum discharge (or charge) power varies from hour to hour according to its state of charge and its recent charge and discharge history, as determined by the kinetic battery model.

Using the kinetic battery model, the maximum amount of power that the battery can discharge over a specific length of time Δt is given by the following equation(User Manual, 2016):

$$P_{batt,d\max,kbm} = \frac{-kcQ_{\max} + kQ_1 e^{-k\Delta t} + Qkc\left(1-e^{-k\Delta t}\right)}{1-e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \text{ -- (6),}$$

where:

Δt is the length of the time step [h].

P is the power [kW] into (positive) or out of (negative) the battery bank using kinetic battery model.

$Q_{\max}$ is the total capacity in kWh of the battery bank.

Q is the total amount of energy in kWh in the battery at the beginning of the time step

k is the rate constant [h^{-1}] which is a measure of how quickly the battery can convert bound energy to available energy or vice-versa.

c is the battery capacity ratio [unitless].

Likewise, the maximum amount of power that the battery can absorb over a specific length of time Δt is given by the following equation(User Manual, 2016):

$$P_{batt,c\max,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1-e^{-k\Delta t}\right)}{1-e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \text{ ------------(7)}$$

j) Mathematical Model of Charge Controller

To prevent overcharging of a battery, a charge controller is used to sense when the batteries are fully charged and to stop or decrease the amount of energy flowing from the energy source to the batteries. The model of the charge controller is presented below (User Manual, 2016):

$$E_{CC-OUT}(t) = E_{CC-IN}(t) \times \eta_{CC} \text{ ---------------------------- (8)}$$

$$E_{CC-IN}(t) = E_{REC-OUT}(t) + E_{SUR-DC}(t) \text{ --------------- (9),}$$

where $E_{CC-OUT}(t)$ is the hourly energy output from charge controller, kWh, $E_{CC-IN}(t)$ is the hourly energy input to charge controller, kWh, η_{CC} is the efficiency of charge controller, $E_{REC-OUT}(t)$ is the hourly energy output from rectifier, kWh, $E_{SUR-DC}(t)$ is the amount of surplus energy from DC sources, kWh (Ani, 2015).

k) Photovoltaic (PV) System

Photovoltaic (PV) Systems generate electricity from sunlight collected by solar panels. Solar panels are available in different shape and size. For instance, the size of the PV system depends on the power requirement of the health facility and its location. PV systems are highly modular, so the system can be customized to cover power demand of the health facility and add units if the power demand increases. PV systems typically have higher capital costs, but lower operating costs when compared to other energy generation options. Solar panels has the lowest O&M cost due to it does not require extensive maintenance; only to remove dust from the panels twice a year (Kassam, 2011).

For the facility under analysis we assumed for the photovoltaic panels a derating factor of 90% and expected lifetime of twenty years as indicated in Figure 10. The cost of PV panels was estimated as US$ 0.600/Wp based on prices cited by Nigerian suppliers (Solar Power Systems Components, 2015). This was adjusted upward to US$ 2/Wp (US$ 2,000 per kWp) to account for other support components that are required, also known as balance of system (BOS) parts, such as cables, charge controller with Maximum Power Point Tracker, lightening protection, as well as delivery/labour and installation costs.

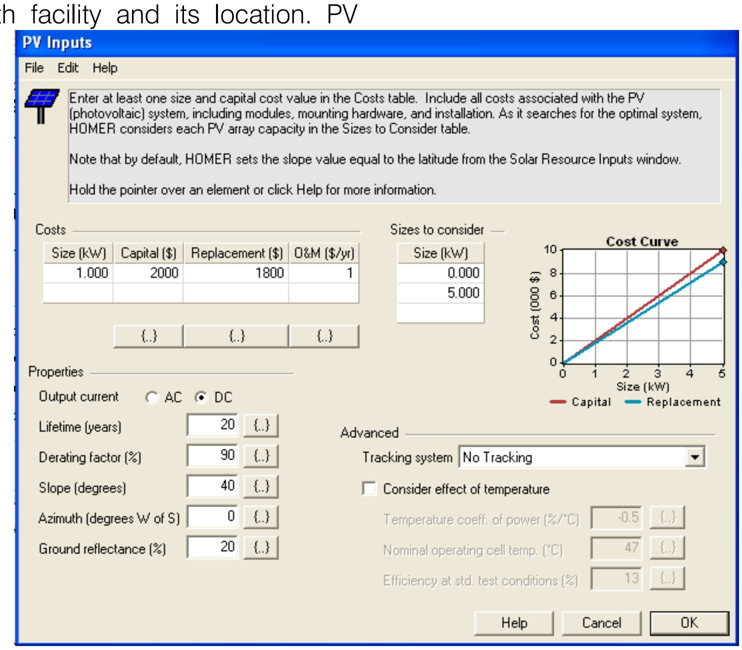


Figure 10: HOMER input for solar photovoltaic

l) Mathematical Model of the Monthly Average Clearness Index andSolar Photovoltaic Generator

HOMER uses the *extraterrestrial horizontal radiation* ($H_{o,ave}$) to calculate either *the monthly average clearness index* (K_T) or *the monthly average global solar radiation* (H_{ave}). For instance, when you enter H_{ave}, HOMER divides it by $H_{o,ave}$ to find K_T. If you enter K_T, HOMER multiplies it by $H_{o,ave}$ to find H_{ave} (User Manual, 2016).

The monthly average clearness index can be calculated using the equation (HOMER help, 2015; User Manual, 2016):

$$K_T = \frac{H_{ave}}{H_{o,ave}} \text{ -- (10),}$$

where:

H_{ave} is the monthly average radiation on the horizontal surface of the earth (kWh/m^2/day)

$H_{o,ave}$ is the *extraterrestrial horizontal radiation*, meaning the radiation on a horizontal surface at the top of the earth's atmosphere (kWh/m^2/day)

Mathematically, the output of the PV array are calculated by HOMER using the following equation(Help Manual, 2015):

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right] \quad \text{------ (11)},$$

where

Y_{PV} is the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

f_{PV} is the PV derating factor [%]

$\overline{G}_T$ is the solar radiation incident on the PV array in the current time step [kW/m^2]

$\overline{G}_{T,STC}$ is the incident radiation at standard test conditions [1 kW/m^2]

α_P is the temperature coefficient of power [%/°C]

T_c is the PV cell temperature in the current time step [°C]

$T_{c,STC}$ is the PV cell temperature under standard test conditions [25 °C]

III. Wind Turbine

Wind Turbine converts the wind energy to the mechanical torque, which rotates the shaft of an electrical generator to generate electrical energy (Hur, 2018; Zammit et al., 2017).The wind turbine in the power system generation can be defined by considering the wind turbine power curve, cut-in speed, and cut-out speed of the wind turbine. HOMER provides a library of several wind turbines already defined to choose from (select), but the wind turbine of ones interest (not found in the library)can be defined (create) based on the manufacturer specifications. By clicking on the wind turbine icon (selected or created) in HOMER, we are able to define the wind turbine used in the power system by entering the quantity (number of wind turbine), Capital Cost, Replacement Cost, Operations & Maintenance (O&M) expenditure, Operating Lifetime, and Hub height of the wind turbine. Full details of the chosen wind turbine can be seen by clicking the 'Details' button.

For the health facility in this exercise, a BWC Excel-R 7.5kW wind turbine (mounted on a standalone monopole) was considered as shown in Figure 11using the default model present in HOMER library. Due to the moving parts, maintenance for wind turbines is somewhat higher than for PV systems.

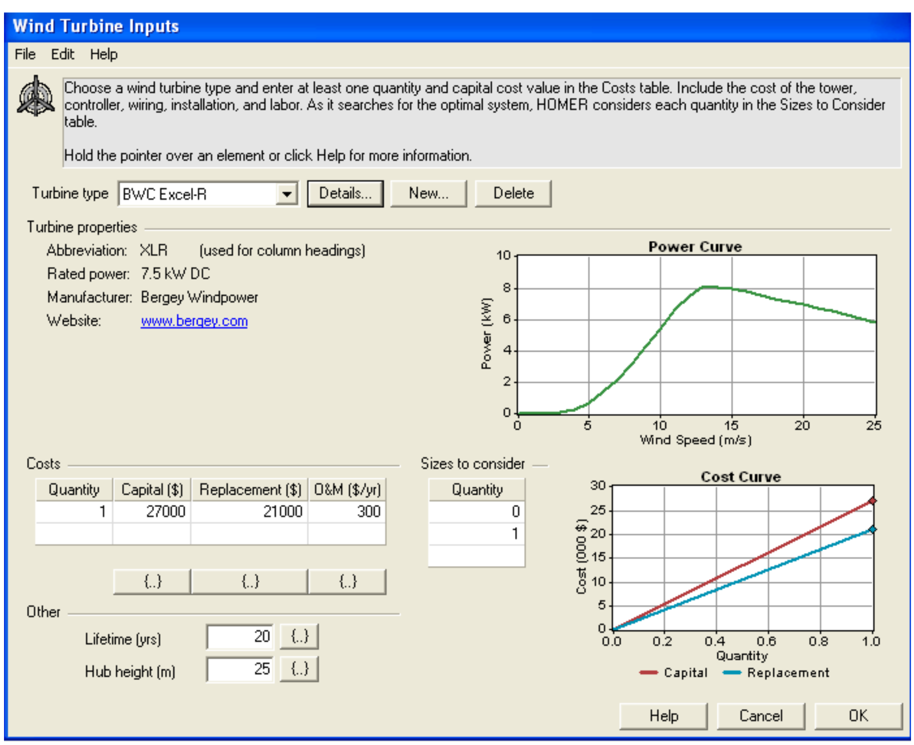


Figure 11: HOMER input for wind turbine

a) Mathematical Model of Wind Energy Generator

Wind speed increases with height above ground. This is because; the ground-level obstacles such as vegetation, buildings, and topographic features tend to slow the wind near the surface. Since the effect of these obstacles decreases with height above ground, wind speeds tend to increase with height above ground. This variation of wind speed with height is called *wind shear*. HOMER uses wind shear to calculate the wind speed at the hub height of the wind turbine. Wind energy engineers typically models wind shear using the logarithmic profile mathematical model.

The logarithmic profile (or log law) assumes that the wind speed is proportional to the logarithm of the height above ground. The following equation gives the ratio of the wind speed at hub height to the wind speed at anemometer height(HOMER help, 2015):

$$\frac{v(z_{hub})}{v(z_{anem})} = \frac{\ln(z_{hub}/z_o)}{\ln(z_{anem}/z_o)} \text{ ---------------------------------- (12),}$$

where:

z_{hub} = the hub height of the wind turbine [m]

z_{anem} = the anemometer height [m]

z_o = the surface roughness length [m]

$v(z_{hub})$ = wind speed at the hub height of the wind turbine [m/s]

$v(z_{anem})$ = wind speed at anemometer height [m/s]

$\ln(...)$ = the natural logarithm

The surface roughness length is a parameter that characterizes the roughness of the surrounding terrain. The representative surface roughness lengths taken from Manwell, McGowan, and Rogers (2002) are shown in Table A2 of the supplementary data.

Step Seven: Calculate Results

HOMER model can be used to compare costs for a variety of different energy generation systems that can meet 100% of this clinic's load. By clicking the Calculate button, the program runs the simulation of different permutations of all possible configurations of system types based on the inputs provided. After the design system had completely simulated, the best possible system configurations will be determined under optimization process. HOMER sorts the feasible cases in order of increasing net present (or lifecycle) cost. This cost is the present value of the initial, component replacement, operation, maintenance, and fuel costs(User Manual, 2016). HOMER lists the optimal system configuration, defined as the one with the least net present cost, for each system type.

In this investigation, and by Ani (2014)an attempt was made to determine for each region and regarding the selected components, which of the mix renewable energy (PV/wind/battery) or hybrid system (PV/wind/diesel/battery; PV/diesel/battery; wind/diesel/battery) is the optimal power system. A 60% renewable fraction was used as criteria for the energy solution. The components needed to satisfy the health facility centre's annual load of 7,082kWh are shown in Figure 12.

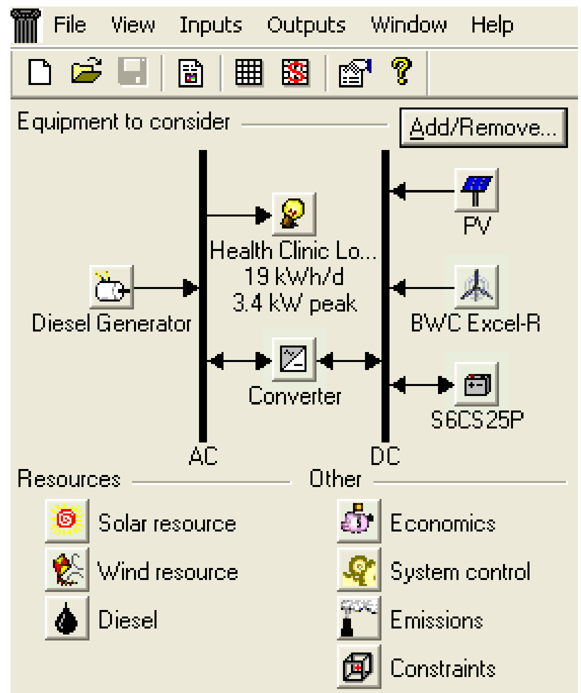


Figure 12: The network architecture (HOMER simulator) for the hybrid energy system of the health facility centre

b) Mathematical Cost Model (Economic & Environmental Costs) of Energy Systems

The equation for estimating the level of optimization of any energy solution being considered for a health clinic and location is derived as below:

c) The Annualized Cost of a Component

The annualized cost of a component includes annualized capital cost, annualized replacement cost, annual O&M cost, emissions cost and annual fuel cost (generator). Operation cost is calculated hourly on daily basis (Ani, 2015):

d) Annualized Capital Cost

The annualized capital cost of a system component is equal to the total initial capital cost multiply by the capital recovery factor. Annualized capital cost is calculated using (Ani, 2015):

$$C_{acap} = C_{cap} \cdot CRF(i, R_{proj}) \text{ ---------------------------- (13),}$$

where:

C_{cap} = initial capital cost of the component

$CRF(i, R_{proj})$ =capital recovery factor

e) Annualized Replacement Cost

The annualized replacement cost of a system component is the annualized value of all the replacement costs occurring throughout the lifetime of the project, minus the salvage value at the end of the project lifetime. Annualized replacement cost is calculated using (Ani, 2015):

$$C_{arep} = C_{rep} \cdot f_{rep} \cdot SFF(i, R_{comp}) - S \cdot SFF(i, R_{proj}) \quad (14)$$

f_{rep}, a factor arising because the component lifetime can be different from the project lifetime, is given by(Ani, 2015):

$$f_{rep} = \begin{cases} CRF(i, R_{proj}) / CRF(i, R_{rep}), & R_{rep} > 0 \\ 0, & R_{rep} = 0 \end{cases} \quad (15)$$

R_{rep}, the replacement cost duration, is given by(Ani, 2015):

$$R_{rep} = R_{comp} \cdot INT\left(\frac{R_{proj}}{R_{comp}}\right) \quad (16),$$

where $INT(\ )$ is the integer function, returning the integer portion of a real value.

$SFF(\ )$, the sinking fund factor is a ratio used to calculate the future value of a series of equal annual cash flows, is given by(User Manual, 2016):

$$SFF(i, N) = \frac{i}{(1+i)^N - 1} \quad (17)$$

The salvage value of the component at the end of the project lifetime is proportional to its remaining life. Therefore the salvage value S is given by(User Manual, 2016):

$$S = C_{rep} \cdot \frac{R_{rem}}{R_{comp}} \quad (18),$$

where R_{rem}, the remaining life of the component at the end of the project lifetime is given by(User Manual, 2016):

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \quad (19),$$

where:

C_{rep} = replacement cost of the component

$SFF(\ )$ = sinking fund factor

i = interest rate

R_{comp} = lifetime of the component

R_{proj} = project lifetime

N = number of years

f) Annualized Operating Cost

The operating cost is the annualized value of all cost and revenues other than initial capital costs and is calculated using (Ani, 2015):

$$C_{aop} = \sum_{t=1}^{365} \left\{ \sum_{t=1}^{24} [C_{oc}(t)] \right\} \quad (20),$$

where $C_{oc}(t)$ is the Cost of operating component.

g) Cost of Emissions

HOMER uses the following equation to calculate the cost of emissions (Ani, 2015; User Manual, 2016):

$$C_{emissions} = \frac{c_{CO_2} M_{CO_2} + c_{CO} M_{CO} + c_{UHC} M_{UHC} + c_{PM} M_{PM} + c_{SO_2} M_{SO_2} + c_{NO_x} M_{NO_x}}{1000} \quad (21),$$

where:

c_{CO_2} = cost for emissions of CO_2 [$/t]

c_{CO} = cost for emissions of CO [$/t]

c_{UHC} =cost for emissions of unburned hydrocarbons (UHC) [$/t]

c_{PM} =cost for emissions of particulate matter (PM) [$/t]

c_{SO_2} =cost for emissions of SO_2 [$/t]

c_{NO_x} =cost for emissions of NO_x [$/t]

M_{CO_2} =annual emissions of CO_2 [kg/yr]

M_{CO} =annual emissions of CO [kg/yr]

M_{UHC} =annual emissions of unburned hydrocarbons (UHC) [kg/yr]

M_{PM} =annual emissions of particulate matter (PM) [kg/yr]

M_{SO_2} = annual emissions of SO_2 [kg/yr]

M_{NO_x} = annual emissions of NO_x [kg/yr]

Total cost of a component = Economic cost + Environmental cost

Where:

Economic cost = Capital cost + Replacement cost + Operation & Maintenance cost + Fuel cost (Generator)

Environmental cost = Emissions cost

Annualized cost of a component is calculated using (Ani, 2015):

$$C_{ann} = C_{acap} + C_{arep} + C_{aop} + C_{emissions} \text{ -- } (22)$$

Annualized total cost of a component is calculated using (Ani, 2015):

$$C_{ann,tot,c} = \sum_{c=1}^{N_c} \left(C_{acap,c} + C_{arep,c} + C_{aop,c} + C_{emissions} \right) \text{ --- } (23),$$

where:

$C_{acap,c}$ = Annualized capital cost of a component

$C_{arep,c}$ = Annualized replacement cost of a component

$C_{aop,c}$ = Annualized operating cost of a component

From equation (23), the Economic and Environmental cost model of running Hybrid (Wind & Solar) + Diesel Generator + Batteries+ Converter is calculated as(Ani, 2015):

$$C_{ann,tot,w+s+g+b+c} = \sum_{w=1}^{N_w} \left(C_{acap,w} + C_{arep,w} + C_{aop,w} + C_{emissions} \right) + \sum_{s=1}^{N_s} \left(C_{acap,s} + C_{arep,s} + C_{aop,s} + C_{emissions} \right) +$$
$$\sum_{g=1}^{N_g} \left(C_{acap,g} + C_{arep,g} + C_{aop,g} + C_{emissions} + C_{afg} \right) + \sum_{b=1}^{N_b} \left(C_{acap,b} + C_{arep,b} + C_{aop,b} + C_{emissions} \right) +$$
$$\sum_{c=1}^{N_c} \left(C_{acap,c} + C_{arep,c} + C_{aop,c} \right) \text{------------------------------------} (24),$$

where:

$C_{acap,w}$ = Annualized Capital Cost of Wind Power

$C_{arep,w}$ = Annualized Replacement Cost of Wind Power

$C_{aop,w}$ = Annualized Operating Cost of Wind Power

$C_{emissions}$ = Cost of Emissions

$C_{acap,s}$ = Annualized Capital Cost of Solar Power

$C_{arep,s}$ = Annualized Replacement Cost of Solar Power

$C_{aop,s}$ = Annualized Operating Cost of Solar Power

$C_{acap,g}$ = Annualized Capital Cost of Diesel Generator

$C_{arep,g}$ = Annualized Replacement Cost of Diesel Generator

$C_{aop,g}$ = Annualized Operating Cost of Diesel Generator

$C_{af,g}$ = Annualized Fuel Cost for Diesel Generator

$C_{acap,b}$ = Annualized Capital Cost of Batteries Power

$C_{arep,b}$ = Annualized Replacement Cost of Batteries Power

$C_{aop,b}$ = Annualized Operating Cost of Batteries Power

$C_{acap,c}$ = Annualized Capital Cost of Converter Power

$C_{arep,c}$ = Annualized Replacement Cost of Converter Power

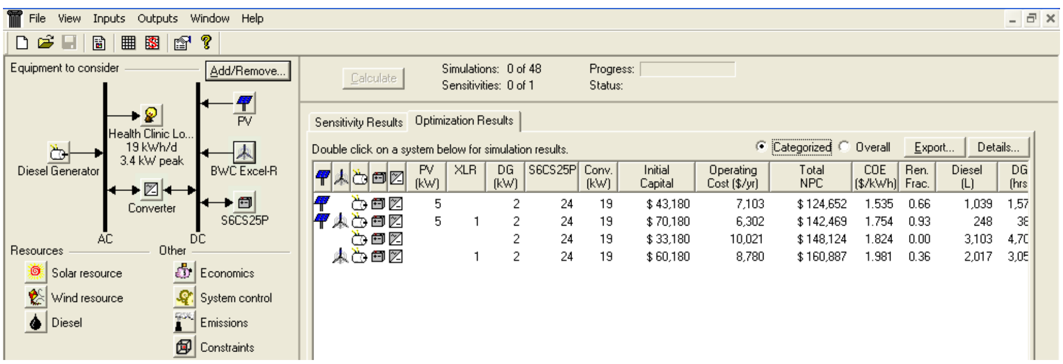
$C_{aop,c}$ = Annualized Operating Cost of Converter Power

The mathematical model derived estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. The output when run with HOMER software/tool will give us the optimal configuration of the energy system that takes into account technical and economic performance of supply options (rated power characteristics for solar Photovoltaic (PV), power curve characteristics for wind turbine (WT), fuel consumption characteristics for diesel generators (DG) and minimum and maximum state of charge (SOC) of a battery bank), the 20-year life cycle cost (LCC) of equipment, locally available energy resources (hourly solar insolation data (W/m^2), hourly wind speed (m/s), as well as cost of fossil fuels), environmental costs, and system reliability.

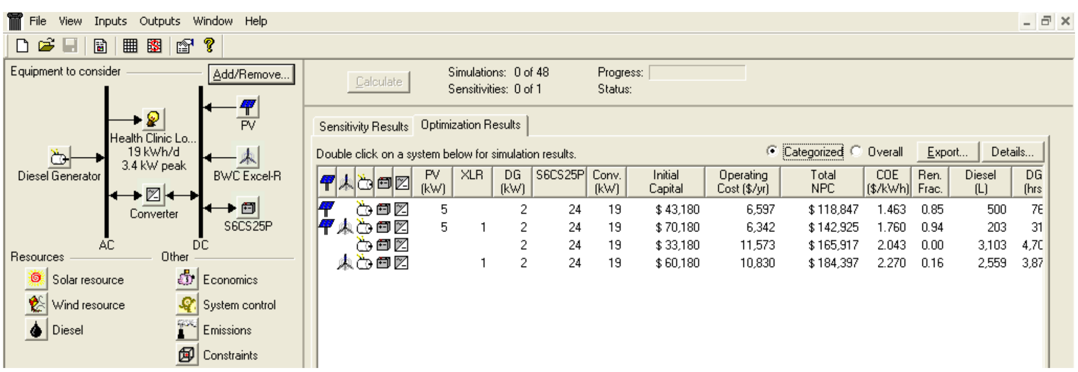
IV. Simulation

Simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time. HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in a year(User Manual, 2016). For each hour, HOMER compares the electric demand of the health facility in the hour to the energy that the system (energy option) can supply in that hour, and calculates the flows of energy to and from each component of the system.

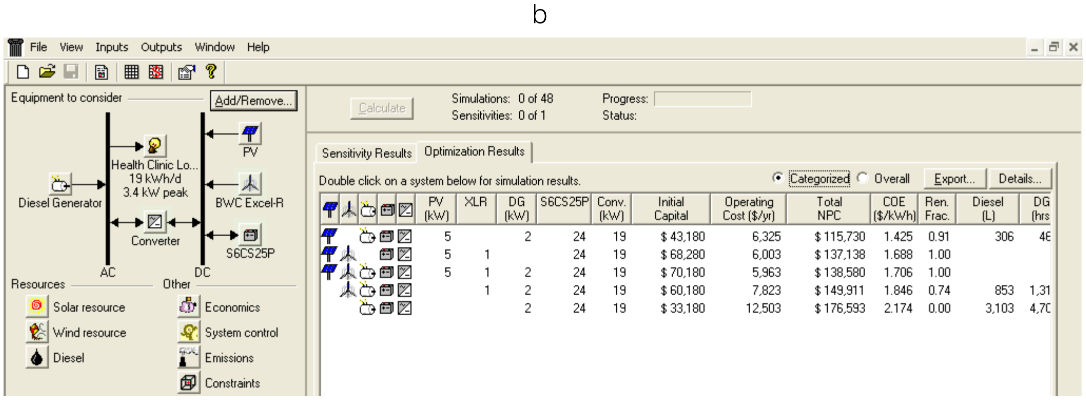
After running the simulations, HOMER sorts the feasible cases in order of increasing NPC (or lifecycle cost). This cost is the present value of the initial, component replacement, operation, maintenance, and fuel costs. HOMER lists the optimal system configuration, defined as the one with the least net present cost, for each system type. It is possible to display the overall (entire) list of configurations or to show the categorized lists (the best solutions from an economic perspective) per system design. Overall list of configuration is the simulation results, while the categorized lists is the optimization results.In this exercise, the optimization result panels in Figure 13 show the categorized list displayed four (a,b) to five (c) different configurations, ordered by most effective NPC.



a



b



c

Figure 13: Optimization result panel for (a) Nembe, (b) Abaji, and (c) Guzamala

By clicking on each of the displayed solution we can access a comprehensive set of data providing high level of detail on each system component such as economical information essential to run a thorough business case. HOMER's main financial output is the total NPC and COE of the examined system(s) configurations (Farid et al., 2017). The Cost summary and Cash Flow details represent a practical starting point for developing a customized business case, including financial indicators such as ROI (Return on Investment), payback period and NPV (Net Present Value), in comparison to the diesel generator only base case that will enable decision makers within health organizations to make accurate investment decisions. In addition it is possible to display many other relevant data concerning renewable (PV and wind turbine) equipment details (i.e. electrical production, hours of operation, etc.), diesel generator (i.e. diesel generator hours of operation, fuel consumption), batteries performances (battery state of charge histogram, etc.), and emissions, etc. These data were organized and presented in the supplementary data.

V. Results and Discussion

Results in the supplementary data (Tables A3 – A14) show that the study of electrification options for the hypothetical health facility at various geographical locations (Nembe (Bayelsa State) in the south, Abaji (Abuja, FCT) in the centre, and Guzamala (Borno State) in the north) in Nigeria illustrate that the percentage of energy generated by both the solar and the wind renewable energy components of each of the hybrid system types tends to vary with the locations of the health facility; and that both the lifetime costof different energy system and the environmental impact of the hybrid energy system types studied vary significantly with the locations of the health facilities due to availability of the renewable energy resources and climatic conditions. Therefore in setting up power system for off-grid rural health facility in Nigeria, the following options were to be chosen based on different regions as this depends on climatic conditions and available renewable energy resources.

- Equatorial Region has two options (PV/diesel, and PV/wind/diesel)
- Tropical Region has also two options (PV/diesel, and PV/wind/diesel)
- Arid Region has four options (PV/diesel, PV/wind, PV/wind/diesel, and wind/diesel)

VI. Conclusion

This paper is a resource for health professionals seeking to electrify health facilities that currently lack power. A case study of a hypothetical off-grid health facility at various geographical locations in Nigeria was used to illustrate the stepwise approach to electrification of health facilities and demonstrate the utility of a modeling tool to assist in the critical task of system design. Information was provided to help the health professionals weigh the pros and cons of various energy systems with a focus on appropriate solutions and special considerations for off-grid rural health clinics. When considering the lifetime cost of different system designs, a modeling program HOMER is a valuable tool. HOMER simplifies the task of determining the most suitable combination of renewable source to supply a given load, and is, therefore, a useful tool in systems load sizing. The product could be used during the process of design, energy analysis and simulation of electrical power process in hybrid and stand-alone systems for energy supply of daily needs and technological processes in health clinics.

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References Références Referencias

1. Acakpovi, A., Hagan E. B., and Michael M. B. (2015). Cost benefit analysis of self-optimized hybrid solar-wind-hydroelectrical energy supply as compared to HOMER optimization. *International Journal of Computer Applications. 114:18. doi: 10. 5120/20081-2133.*
2. Adetunji K. E., Akinlabi O.A., &Joseph M. K. (2018) Developing a Microgrid for Tafelkop using HOMER. 2018 International Conference on Advances in Big Data, Computing and Data Communication Systems (ICABCD) IEEE 2018
3. Al Garni, H.Z., Awasthi, A., & Ramli, M.A (2018). Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER. *Energy Convers. Manag. 2018, 155, 42–57.*
4. Al-Hamdani A. H., Dawood A. F., Abdullah K. N., & Mousaui S.M. (2016), "Optimal sizing of photovoltaic systems using HOMER for Baghdad," *International Journal of Computation and Applied Sciences*, vol. 1, no. 2, pp. 1–6, 2016.
5. Ani, Vincent Anayochukwu (2015) *Energy Optimization At GSM Base Station Sites Located In Rural Areas.*Doctoral Dissertation, University of Nigeria, Nsukka (UNN).
6. Ani, Vincent Anayochukwu (2014) Energy Optimization Map for Off-Grid Health Clinics in

Nigeria. *International Journal of Renewable Energy Research (IJRER), Vol. 4, No. 1.*
7. Ani, Vincent Anayochukwu & Emetu, Alice Nnene (2013), Simulation and Optimization of Photovoltaic/Diesel Hybrid Power Generation System for Health Service Facilities in Rural Environments *Electronic Journal of Energy and Environment (EJEE) Vol. 1, No. 1, DOI: 10.7770/ejee-V1N1-art521*
8. Ansong, M., Mensah, L.D., & Adaramola, M.S (2017). Techno-economic analysis of a hybrid system to power a minein an off-grid area in Ghana. *Sustain. Energy Technol. Assess. 2017, 23, 48–56.*
9. Babatunde, O., Munda, J., & Hamam, Y., (2019) Decarbonisation of Electricity Generation: Efforts and Challenges. In Carbon Footprints; Springer: Berlin/Heidelberg, Germany, pp. 47–77.
10. Badawe M.E., Iqbal T. & Mann G.K (2012). Optimization and a comparison between renewable and non-renewable energy systems for a telecommunication site. In: 25th IEEE Canadian conference on electrical and computer engineering (CCECE), Montreal, Canada, April 29 -May 2, 2012. IEEE, pp. 1-5
11. Bahramara, S., Moghaddam, M.P., & Haghifam, M.R. (2016) Optimal planning of hybrid renewable energy systems using HOMER: A review. *Renew. Sustain. Energy Rev. 2016, 62, 609–620.*
12. Bekelea G. & Boneya G., (2011). Design of a photovoltaic-wind hybrid power generation system for Ethiopian remote area. *Energy Procedia* 6, 1760-1765.
13. Bernal-Agustín J.L., Dufo-López R. & Rivas-Ascaso D.M., (2006). Design of isolated hybrid systems minimizing costs and pollutant emissions. *Renewable Energy 31(14), 2227-2244.*
14. Budes Farid Antonio Barrozo, Ochoa Guillermo Valencia, Obregon Luis Guillermo, Arango-Manrique Adriana & Núñez ÁlvarezJosé Ricardo (2020) Energy, Economic, and Environmental Evaluation of a Proposed Solar-Wind Power On-grid System Using HOMER Pro®: A Case Study in Colombia.*Energies 2020, 13, 1662; doi:10.3390/en13071662*
15. Cristian H., Bizon N., & Alexandru B., (2017). Design of hybrid powers ystems using HOMER simulator for different renewable energy sources, in *Electronics, Computers and Artificial Intelligence(ECAI), 2017 9th International Conference on*, pp. 1-7, 2017.
16. Deepak, Lal Kumar, Dash Bibhuti Bhusan, &Akella, A. K. (2011), Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area. *International Journal on Electrical Engineering and Informatics 3.3 (2011): 307-325.*
17. Deshmukha M. K., & Singha Athokpam Bharatbushan (2019). Modeling of Energy Performance of Stand-Alone SPV System Using HOMER Pro. 2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan. *Energy Procedia 156 (2019) 90–94*
18. Farid Barrozo Budes, Guillermo Valencia Ochoa& Yulineth Cárdenas Escorcia (2017) An Economic Evaluation of Renewable and Conventional Electricity Generation Systems in a Shopping Center Using HOMER Pro® *Contemporary Engineering Sciences, Vol. 10, No. 26, 1287 - 1295* https://doi.org/10.12988/ces. 2017.710149
19. Getting started guide for Homer version 2.1 –(2005) National Renewable - National Renewable Energy Laboratory. Retrieved April 12, 2020, from https://www.homerenergy.com/pdf/HOMER2_2.1_HelpManual.pdf
20. Halabi, L.M., Mekhilef, S., Olatomiwa, L., & Hazelton, J (2017). Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study Sabah, Malaysia. *Energy Convers. Manag. 2017, 144, 322–339.*
21. Hassan Q., Jaszczur M., & Abdulateef J., (2016) "Optimization of PV/wind/diesel hybrid power system in homer for rural electrification," in *Journal of Physics: Conference Series*, 2016, vol. 745, no. 3, p.032006.
22. HOMER Help Manual (2015) Retrieved April 06, 2020, from https://www.homerenergy.com/pdf/HOMER2_2.8_HelpManual.pdf
23. HOMER Pro Version 3.7 User Manual (2016) Retrieved July 15, 2020, from https://www.homerenergy.com/pdf/HOMERHelpManual.pdf
24. Hur, S., (2018). Modelling and control of a wind turbine and farm. *Energy 156, 360–370.*
25. Hybrid Optimization Model for Electric Renewables – HOMER help, (2015). Retrieved April 12, 2020, from http://www.nrel/gov/HOMER
26. Jamalaiah A., Raju C. P., & Srinivasarao R., (2017) "Optimization and operation of a renewable energy based pv-fc-micro grid using homer," in *2017International Conference on Inventive Communication and Computational Technologies (ICICCT)*, 2017, pp.450–455.
27. Kassam Areef, (2011) HOMER Software Training Guide for Renewable Energy Base Station Design. Retrieved January 01, 2020, from http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/06/HOMER-Software-Training-Guide-June-2011.pdf
28. Kusakana K. and Vermaak H.J., (2013). Hybrid renewable power systems for mobile telephony base stations in developing countries. *Renewable Energy 51, 419-25.*
29. Li C., Ge X.F., Zheng Y., Xu C., Ren Y., Song C.G. and Yang C.X., (2013). Techno economic feasibility study of autonomous hybrid wind/PV/battery power

system for a household in Urumqi, China. *Energy, 55, 263-272.*

30. Madziga, M.; Rahil, A.; Mansoor, R (2018). Comparison between three off-grid hybrid systems (solar photovoltaic, diesel generator and battery storage system) for electrification for Gwakwani village, South Africa. *Environments 2018, 5, 57.*
31. Malika Amini, Renewable Energy Systems for Rural Health Clinics in Algeria: Homer Application Retrieved January 01, 2020, from www.homer energy.com/webcast-downloads/Malika_Amini/ health.pdf
32. Manwell JF, McGowan JG, &Rogers AL (2002) *Wind Energy Explained,* Wiley, New York, NY
33. Manwell JF, &McGowan JG (1993) Lead acid battery storage model for hybrid energy systems, *Solar Energy*, 50, 399-405
34. Mohammed M., Aziz A., Alwaeli A. H., & Kazem H. A., (2013) "Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman," *International Journal of Renewable Energy Research(IJRER),* vol. 3, pp. 470-475, 2013.
35. Nagger Hassan, Khaled Abd El_Atey & Amr Hosny Mohammed El_Enany (2018) Economically Optimal Design of Hybrid Renewable Energy Systems Using HOMER and ACO. Journal of Al Azhar University Engineering Sector, Vol. 13, No. 48, July 2018, 1016-1030
36. Ngan M.S. and Tan C.W., (2012). Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. *Renewable and Sustainable Energy Reviews 16, 634-647.*
37. Olubayo M. Babatunde, Josiah L. Munda & Yskandar Hamam (2019). Selection of a Hybrid Renewable Energy Systems for a Low-Income Household. *Sustainability 2019, 11, 4282; doi:10.3390/su11164282*
38. Partha Sarothi Sikder, &Nitai Pal (2020). Modeling of an intelligent battery controller for standalone solar-windhybrid distributed generation system. *Journal of King Saud University – Engineering Sciences 32, 368–377*
39. Rajbongshi R., Borgohain D., & Mahapatra S., (2017) “Optimization of PV-biomass-diesel and grid base hybrid energy systems for rural electrification by using HOMER,” *Energy*, vol. 126, pp. 461–474.
40. Razmjoo Ali & Davarpanah Afshin (2018). Developing various hybrid energy systems for residential application as an appropriate and reliable way to achieve Energy sustain ability, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.* https://doi.org/10.1080/ 15567036.2018.1544996
41. Rezzouk, H.; Mellit, A (2015). Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria. *Renew. Sustain. Energy. Rev., 43, 1134–1150.*
42. Rohit Sen & Subhes C. Bhattacharyya, (2014) “Off-grid electricity generation with renewable energy technologies in India: AN application of HOMER”, *Renewable Energy*, 62 (2014): 388-398, http://dx.doi.org/10.1016/j.renene.2013.07.028
43. Ronad B. F. & Jangamshetti S. H., (2015) “Optimalcost analysis of wind-solar hybrid system powered AC and DC irrigation pumps using HOMER,” in *2015International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015, pp. 1038–1042.
44. Shahinzadeh Hossein, Moazzami Majid, Fathi Hamid S., & Gharehpetian Gevork B. (2016) Optimal Sizing and Energy Management of a Grid-Connected Microgrid using HOMER Software. 2016 Smart Grids Conference (SGC), 20-21 Dec. 2016, Graduate University of Advanced Technology, Kerman, Iran
45. Shahinzadeh, Hossein, Gharehpetian Gevork B., Fathi S. Hamid, & Nasr-Azadani Sayed Mohsen (2015a). "Optimal Planning of an Off-grid Electricity Generation with Renewable Energy Resources using the HOMER Software." *International Journal of Power Electronics and Drive Systems* 6, no. 1 (2015): 137.
46. Shahinzadeh, Hossein., Fathi S. Hamid & Nasr-Azadani Sayed Mohsen (2015b). "Optimal Sizing of PV/Wind Hybrid Systems to Energy Supply of Street Lighting by using HOMER Software (A Case Study inYazd)." *In 2015 The 3rd National Conference on Climate, Building and Energy Efficiency*, 13-14 May 2015.
47. Shezan S.K.A. and Ping H.W. (2017). Techno-Economic and Feasibility Analysis of a Hybrid PV-Wind-Biomass-Diesel Energy System for Sustainable Development at Offshore Areas in Bangladesh. *Current Alternative Energy, 1, 20-32*
48. Shezan S.K.A., Julai S., Kibria M.A., Ullah K.R., Saidur R., Chong W.T., Akikur R.K. (2016) Performance analysis of an off-grid wind-PV (photovoltaic)-diesel battery hybrid energy system feasible for remote areas. *Journal of Cleaner Production 125, 121e132*
49. Sigarchian, S.G.; Paleta, R.; Malmquist, A.; Pina, A (2015). Feasibility study of using a biogas engine as backup in a decentralized hybrid (PV/wind/battery) power generation system—Case study Kenya. *Energy, 90, 1830–1841.*
50. Solar Power Systems Components – Solar Panels Prices in Nigeria Retrieved July 15, 2020, from www.naijatechguide.com/2008/11/solar
51. United States Agency for International Development (USAID),Powering Health: Electrification Options for Rural Health Centers Retrieved January 01, 2020, from www.poweringhealth.org/Pubs/PNADJ557.pdf

52. World Health Organization (WHO) - (2016) Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings: A Review of Status, Significance, Challenges and Measurement www.apps.who.int/iris/bitstream/10665/156847/1/9789241507646_eng.pdf
53. World Health Organization (WHO) – (2014) *Access to modern energy services for health facilities in resource-constrained settings*, Geneva, World Health Organization, 2014. http://www.who.int/hia/green_economy/modern-energy-services/en/
54. Zahboune, H., Zouggar, S., Krajacic, G., Varbanov, P.S., Elhafyani, M., & Ziani, E. (2016) Optimal hybrid renewableenergy design in autonomous system using Modified Electric System Cascade Analysis and Homer software.*Energy Convers. Manag. 2016, 126, 909–922.*
55. Zammit, D., Staines, C.S., Micallef, A., Maurice, A., & Lieari, J., (2017). Incremental current based MPPT for a PMSG micro wind turbine in a grid-connected DCmicrogrid. *Energy Procedia. 142, 2284–2294.*

Supplementary Data

Electrical Load Data

Table A1: The electrical load (Power supply requirements) data for a Health facility

S. No.	Power Consumption	Power (Watts)	Qty	Load (watt x qt)	Hours/day	On-Time (Time in Use)
1	Vaccine Refrigerator/Freezer	60	1	60	24	(0.00hr – 23.00hr)
2	Small Refrigerator (non-medical use)	300	1	300	5	(10.00hr – 15.00hr)
3	Centrifuge	575	1	575	2	(12.00hr – 14.00hr)
4	Hematology Mixer	28	1	28	2	(10.00hr – 12.00hr)
5	Microscope	15	1	15	5	(09.00hr – 14.00hr)
6	Security light	10	4	40	12	(18.00hr – 6.00hr)
7	Lighting	10	2	20	7	(09.00hr – 16.00hr)
8	Sterilizer Oven (Laboratory Autoclave)	1,564	1	1,564	1	(12.00hr – 13.00hr)
9	Incubator	400	1	400	24	(0.00hr – 23.00hr)
10	Water Bath	1,000	1	1,000	1	(14.00hr – 15.00hr)
	Communication via VHF Radio		1			
11	Stand-by	2		2	24	(0.00hr – 23.00hr)
12	Transmitting	30		30	4	(09.00hr – 13.00hr)
13	Desktop Computer	200	2	400	5	(09.00hr – 14.00hr)
14	Printer	65	1	65	3	(09.00hr – 10.00hr; 13.00 – 15.00hr)

Table A2: Surface roughness lengths (Manwell, McGowan, and Rogers, 2002)

Terrain Description	z_0
Very smooth, ice or mud	0.00001 m
Calm open sea	0.0002 m
Blown sea	0.0005 m
Snow surface	0.003 m
Lawn grass	0.008 m
Rough pasture	0.010 m
Fallow field	0.03 m
Crops	0.05 m
Few trees	0.10 m
Many trees, few buildings	0.25 m
Forest and woodlands	0.5 m
Suburbs	1.5 m
City center, tall buildings	3.0 m

Power System Configurations

Table A3: Power system configurations for *Equatorial region (Nembe)*

Configurations	PV	BWC Excel-R Wind turbine	Diesel Generation	Surrette 6CS25P Battery	Converter	Renewable fraction (%)
PV/Diesel/Batt/Conv	5kW		2kW	24 units	19kW	66*
PV/Wind/Diesel/Batt/Conv	5kW	7.5kW	2kW	24 units	19kW	93*
Diesel/Batt/Conv			2kW	24 units	19kW	0
Wind/Diesel/Batt/Conv		7.5kW	2kW	24 units	19kW	36

*Significant renewable fraction exceeding 60%

Table A4: Power system configurations for *Tropical region (Abaji)*

Configurations	PV	BWC Excel-R Wind turbine	Diesel Generation	Surrette 6CS25P Battery	Converter	Renewable fraction (%)
PV/Diesel/Batt/Conv	5kW		2kW	24 units	19kW	85*
PV/Wind/Diesel/Batt/Conv	5kW	7.5kW	2kW	24 units	19kW	94*
Diesel/Batt/Conv			2kW	24 units	19kW	0
Wind/Diesel/Batt/Conv		7.5kW	2kW	24 units	19kW	16

*Significant renewable fraction exceeding 60%

Table A5: Power system configurations for *Arid region (Guzamala)*

Configurations	PV	BWC Excel-R Wind turbine	Diesel Generation	Surrette 6CS25P Battery	Converter	Renewable fraction (%)
PV/Diesel/Batt/Conv	5kW		2kW	24 units	19kW	91*
PV/Wind/Batt/Conv	5kW	7.5kW		24 units	19kW	100*
PV/Wind/Diesel/Batt/Conv	5kW	7.5kW	2kW	24 units	19kW	100*
Wind/Diesel/Batt/Conv		7.5kW	2kW	24 units	19kW	74*
Diesel/Batt/Conv			2kW	24 units	19kW	0

*Significant renewable fraction exceeding 60%

Simulation Results of Economic Cost

Table A6: Simulation results of Economic cost for *Equatorial region (Nembe)*

Parameter	PV/Diesel/ Batt/Conv	PV/Wind/Diesel/ Batt/Conv	Diesel/ Batt/Conv	Wind/Diesel/ Batt/Conv
Initial Cost	$43,180	$70,180	$33,180	$60,180
Operating Cost ($/yr)	7,103	6,302	10,021	8,780
Total NPC	$124,652	$142,469	$148,124	$160,887

Table A7: Simulation results of Economic cost for *Tropical region (Abaji)*

Parameter	PV/Diesel/ Batt/Conv	PV/Wind/Diesel/ Batt/Conv	Diesel/ Batt/Conv	Wind/Diesel/ Batt/Conv
Initial Cost	$43,180	$70,180	$33,180	$60,180
Operating Cost ($/yr)	6,597	6,342	11,573	10,830
Total NPC	$118,847	$142,925	$165,917	$184,397

Table A8: Simulation results of Economic cost for *Arid region (Guzamala)*

Parameter	PV/Diesel/ Batt/Conv	PV/Wind/ Batt/Conv	PV/Wind/Diesel/ Batt/Conv	Wind/Diesel/ Batt/Conv	Diesel/ Batt/Conv
Initial Cost	$43,180	$68,280	$70,180	$60,180	$33,180

Operating Cost ($/yr)	6,325	6,003	5,963	7,823	12,503
Total NPC	$115,730	$137,138	$138,580	$149,911	$176,593

Simulation Results of Electricity Production

Table A9: Simulation results of Electricity production for *Equatorial region (Nembe)*

Parameter	PV/Diesel	PV/Wind/Diesel	Diesel	Wind/Diesel
PV	(6,220) 66%	(6,220) 60%	0%	0%
Wind	0%	(3,385) 33%	0%	(3,385) 36%
Diesel	(3,146) 34%	(750) 7%	(9,402) 100%	(6,112) 64%
Total	(9,366) 100%	(10,355) 100%	(9,402) 100%	(9,497) 100%

Table A10: Simulation results of Electricity production for *Tropical region (Abaji)*

Parameter	PV/Diesel	PV/Wind/Diesel	Diesel	Wind/Diesel
PV	(8,493) 85%	(8,493) 80%	0%	0%
Wind	0%	(1,502) 14%	0%	(1,502) 16%
Diesel	(1,512) 15%	(614) 6%	(9,402) 100%	(7,756) 84%
Total	(10,005) 100%	(10,608) 100%	(9,402) 100%	(9,258) 100%

Table A11: Simulation results of Electricity production for *Arid region (Guzamala)*

Parameter	PV/Diesel	PV/Wind	PV/Wind/Diesel	Wind/Diesel	Diesel
PV	(9,138) 91%	(9,138) 55%	(9,138) 55%	0%	0%
Wind	0%	(7,490) 45%	(7,490) 45%	(7,490) 74%	0%
Diesel	(925) 9%	0%	0%	(2,568) 26%	(9,402) 100%
Total	(10,062) 100%	(16,628) 100%	(16,628) 100%	(10,058) 100%	(9,402) 100%

Simulation Results of Environmental Impact

Table A12: Simulation results of Environmental impact for *Equatorial region (Nembe)*

Parameter	PV/Diesel	PV/Wind/Diesel	Diesel	Wind/Diesel
Fuel Consumption (L)	1,039	248	3,103	2,017
Hour of diesel consumption (hrs)	1,578	380	4,701	3,056
Carbon dioxide (kg/yr)	2,736	654	8,170	5,311
Carbon monoxide (kg/yr)	6.75	1.61	20.2	13.1
Unburned hydrocarbon (kg/yr)	0.748	0.179	2.23	1.45
Particulate matter (kg/yr)	0.509	0.122	1.52	0.988
Sulphur dioxide (kg/yr)	5.49	1.31	16.4	10.7
Nitrogen oxides (kg/yr)	60.3	14.4	180	117

Table A13: Simulation results of Environmental impact for *Tropical region (Abaji)*

Parameter	PV/Diesel	PV/Wind/Diesel	Diesel	Wind/Diesel
Fuel Consumption (L)	500	203	3,103	2,559
Hour of diesel consumption (hrs)	764	311	4,701	3,878

Carbon dioxide (kg/yr)	1,317	535	8,170	6,740
Carbon monoxide (kg/yr)	3.25	1.32	20.2	16.6
Unburned hydrocarbon (kg/yr)	0.36	0.146	2.23	1.84
Particulate matter (kg/yr)	0.245	0.0996	1.52	1.25
Sulphur dioxide (kg/yr)	2.65	1.07	16.4	13.5
Nitrogen oxides (kg/yr)	29	11.8	180	148

Table A14: Simulation results of Environmental impact for *Arid region (Guzamala)*

Parameter	PV/Diesel	PV/Wind	PV/Wind/Diesel	Wind/Diesel	Diesel
Fuel Consumption (L)	306	0	0	853	3,103
Hour of diesel consumption (hrs)	466	0	0	1,318	4,701
Carbon dioxide (kg/yr)	805	0	0	2,246	8,170
Carbon monoxide (kg/yr)	1.99	0	0	5.54	20.2
Unburned hydrocarbon (kg/yr)	0.22	0	0	0.614	2.23
Particulate matter (kg/yr)	0.15	0	0	0.418	1.52
Sulphur dioxide (kg/yr)	1.62	0	0	4.51	16.4
Nitrogen oxides (kg/yr)	17.7	0	0	49.5	180

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Social-Economic Effects and Political Satisfaction from Pedestrian Footbridges in Rural Areas

By Claude Munyaneza & Leopold Mbereyaho
University of Rwanda

Abstract- It is generally accepted that having a proper river crossing point has a positive effect on rural inhabitants. Such crossing points would increase the ability of communities to access their social services, markets, jobs, and thereby lead to raising their standard of living. In line with this objective, Rwanda has been promoting the construction of pedestrian footbridges in rural areas, and with different partners, different pedestrian footbridges have already been constructed. It is very crucial that all institutions involved in the construction of pedestrian footbridges, both public and private, consider the financial benefits of pedestrian footbridges and some significant direct and indirect effects on the rural communities. The Objective of this study was to identify all possible benefits that may be generated by pedestrian footbridges to understand the potential range of their impacts in rural areas and the likely responses from those people impacted by the project. The study also proposed a comprehensive approach for estimating the economic impacts of a pedestrian footbridge in rural areas. The methodology involved community interviews conducted during site visits to identify and predict possible impacts due to the lack and availability of safe access via pedestrian footbridges.

Keywords: political satisfaction, pedestrian footbridge, bridges to prosperity, social-economic effects.

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SOCIALECONOMICEFFECTSANDPOLITICALSATISFACTIONFROMPEDESTRIANFOOTBRIDGESINRURALAREAS

Strictly as per the compliance and regulations of:

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Claude Munyaneza α & Leopold Mbereyaho σ

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Keywords: political satisfaction, pedestrian footbridge, bridges to prosperity, social-economic effects.

I. Introduction

Adequate access to social-economic facilities and services, as hospitals, schools, and shopping centers, etc., for many people living in rural areas, has been one of development goals in developing countries. One of the most affordable and viable alternatives means against rural isolation is the construction of pedestrian footbridges. The protection of people as they go about their everyday lives in their neighborhoods or workplaces may be influenced by improvement in transportation systems [1].

A pedestrian-friendly environment can be transformed by unsafe river crossing points or changes in traffic habits that place residents at higher risk of injury or death. Such changes need consideration of adequate and safe crossing points for pedestrians, animals, bicycles, and motorcycles.

As a developing country, Rwanda is committed to addressing the problem of inadequate pedestrian footbridges in rural areas, resulting from its geographical conditions. In partnership with districts and other public and private institutions, an International Non-Governmental Organization, Bridges to Prosperity (B2P), which is specialized in the design and construction of pedestrian footbridges, has been constructing pedestrian footbridges for the past nine years. B2P's contribution has resulted in 95 bridges implemented in different districts of Rwanda to serve over 400,000 people. Per an agreement with the Government of Rwanda, over 100 more are to be completed over the next three years [2].

Although the immediate impacts of Pedestrian footbridges in rural areas, such as transport costs, travel time, and improved safety, are clear, there are long-term impacts such as increased profitability of farmers and business revenue change, as well as increased employment in the agricultural and non-agricultural sectors. It should be also emphasized that the development of rural infrastructure, whether physical or nonphysical, not only improves local economic capacity, but also plays a direct and indirect role in reducing poverty [3].

It is necessary that all institutions involved in the construction of pedestrian footbridges, both public and private, are well aware of the value and benefits of the pedestrian footbridges to rural communities which may have significant indirect effects on rural communities, which could result from the direct effects. It is clear that while a pedestrian footbridge can allow the crossing of respective obstacles by communities, it boosts their economy and the national economy in general. As a result, it directly affects the political trust of the communities and the development of the country. Therefore, a comprehensive approach for estimating the social-economic effects of a pedestrian footbridge in

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rural areas is indispensable to understand the importance of investment in rural pedestrian infrastructure.

The aim of social-economic impact assessment is to enable the government and other key stakeholders to recognize and better predict the potential social-economic impacts from proposed projects, strategies, and services for human populations and communities [4].

Some researchers have conducted studies on how pedestrian footbridges can improve rural economies. [5] concluded that the construction of new pedestrian footbridge crossings links rural and underserved communities in developing countries worldwide with the services they need.
Some potential indirect effects, such as general economic conditions of an area or region, the availability of municipal services, like sewer and water, the tax incremental, and the quality of life, could occur beyond the project's actual right of way [6].

Pedestrian footbridges have a demonstrated impact well beyond the two communities they connect. A study of the total geographic area served by one single pedestrian footbridge in Rwanda resulted in an average of 33 unique villages covering 47 square kilometers of mountainous terrain when considering the reported origins and destinations. An average catchment area of 17 villages was then estimated with the adjustment to reflect only journeys in service of livelihoods, health, and education [7]. A study about the methods to identify pedestrian footbridge needs in rural areas of Liberia and Rwanda recommended a mixed approach that combines both sophisticated remote methods with streamlined field-based methods that consider the existing local knowledge and expertise and cataloged the extensive need for safe access throughout rural areas, as well as the destinations that deemed critical by communities, but difficult to reach due to seasonally impassible rivers [8].

The possibility of creating a sustainable national Pedestrian footbridge program with the support of a comprehensive Pedestrian footbridge management system was documented in 2020 by Claude Munyaneza. and Leopold Mbereyaho. Analysis of condition data, determination of the ranking and priority of bridge maintenance activities, as well as evaluation of the alternatives of preservation or replacement create an environment where Pedestrian footbridges may be effectively built and maintained [9].

In 2020, Brooks and Donovan published their findings of a study about the impact of new bridges in rural Nicaragua, which found that lack of reliable outside market access can have a significant effect on rural economies' long-term agricultural decisions, and infrastructure benefits go beyond the ability to move products more efficiently through space. Pedestrian footbridges improve accessibility to labor markets, which may decrease distortions in the agricultural sector [10]. Such access to local businesses increases the safety within the community and generally enhances the quality of life for residents [11]. This results in both social capitals as well as economic fairness evaluations which have significant effects on political trust [12].

The Objective of this study was to identify all possible benefits resulting from pedestrian footbridge construction to understand the range of potential impacts of a new pedestrian footbridge in rural areas and the likely responses of those impacted by the projects, to highlight rural pedestrian and motorcycle transport as an effective strategy for rural economic development. The study also proposed a comprehensive approach for estimating the economic impacts of a pedestrian footbridge in rural areas.

II. Methods

a) Methodology Description

In addition to the literature review, which provided an opportunity to understand the situation globally and locally and note the gaps, the methodology used in this study involved community interviews and feedback analysis. Interviews and discussions with 980 people, including 30 local leaders, ten bridge builders from B2P, and 940 local communities who are mostly the beneficiaries of constructed pedestrian footbridges in different districts, were held to understand and determine how they are impacted by the pedestrian footbridges. The questionnaire was structured so that information concerning changes of lives before and after the construction of pedestrian footbridge as well as expectations before the project were acquired. Observations made during the site visits helped to identify or predict the impacts of blocked access, and safe crossings. Microsoft Excel analysis tools developed the estimating approach of pedestrian footbridge benefits for rural communities with established formulas. During the site visit, five pedestrian footbridges under the operation stage were selected. The analysis involved the social and economic effects. Social effects were analyzed into four main categories such as accessibility and connectivity, health and safety, an increase of income and reduction of cost, and cultural well-being. The economic effects were analyzed in two main categories: economic impact from user cost and the overall economic benefits.

Using statistical analysis software of Rao soft, five pedestrian footbridges were all assessed for their social-economic and political satisfaction effects. Finally, one bridge was taken as a case study for the economic impact assessment.

b) Identification and Analysis of Estimated Effects

A Synthesis of interviews, background information, and observations made during the site visits were included in this process. This required the

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identification and prediction of effects without the pedestrian footbridge and with the pedestrian footbridge in the area. This study focused on identifying social-economic impact during the operation stage of a pedestrian footbridge, to gain an understanding before and following pedestrian footbridges construction.

c) Community Interest

The community interest for this study has been informed by several sources. Several interested people were selected because they identified as directly benefiting from the constructed bridges. Additionally, most used the bridges to access their daily social-economic activities. For analyzing the effects of the project during the construction stage, the communities who participated in all construction stages were also considered.

The community of interest was further informed by a demographic analysis of a wider geographic study area, identifying social and community infrastructure and facilities within the study area, particularly those close to the bridge. The demographic study area was selected to analyze the characteristics of residents and communities within the catchment who were most likely to experience effects as a result of the bridge and assist in the identification of potential community groups that may have been affected by the bridge project, particularly those which are not in direct proximity to the bridge project.

Input from the wider community of interest was then sought through further engagement with identified community groups and the general public. This included feedback provided by face-to-face interviews and open day discussions and feedback.

d) Social-Economic Impact Assessment Criteria

Referring to the relevant categories of the International Association for Impact Assessment (IAIA) framework [13], the following framework has been established for assessing the potential impacts that may result from a Pedestrian footbridge project:

Way of Life:

- Impacts on accessibility, connectivity, living habits, and mobility
- Changes to ways of crossing (walking and cycling)

Well, Being:

- Changes to wellbeing
- Health and safety

Financial:

- Change of market price
- Benefit increase from agriculture productivity
- Making Money

e) Rating of Effects

In assessing effects, each effect has been given an overall rating of impacts. A four-point scale has been applied, and the ratings applied are:

- Significant positive
- Moderate positive
- Minor positive
- Insignificant

In applying the overall rating of the effects, consideration was given to: the project stage of the effect (construction, operational, or both), who is affected (directly affected, neighbors, wider community), the probability of occurrence (high, medium, or low), and the magnitude of the impact (high, medium, low), and the significance of the affected feature (local, regional, national) [14].

III. Results

a) Results from the Interview

i. *Demographic Profile of Respondents*

As mentioned in section 2, the total number of participants for this study was 980 people, including 30 local leaders, ten bridge builders from B2P, and 940 local communities. They are mostly the beneficiaries of the constructed pedestrian footbridge in the area. Their demographic profile was considered into three main categories, as summarized in Table 1 below. These include the age distribution, gender composition, and primary occupation.

Table 1: Demographic Profile for Participants

Age Distribution		Percentage	Gender Composition		Primary Occupation			
Age group	Number	%	Male	Female	Agriculture	Business people	Salaried Employee	Students
4_12	54	5.51	32	22	0	0	0	54
13_21	47	4.80	16	31	12	2	1	32
22_30	179	18.27	105	74	129	30	18	2
31_39	245	25	108	137	187	36	22	0
40_48	233	23.78	104	129	204	16	13	0

49_57	155	15.82	77	78	140	9	6	0
58+	67	6.84	32	35	62	4	1	0
TOTAL	**980**	**100**	**474**	**506**	**734**	**97**	**61**	**88**

ii. *Social-Economic Effects of Pedestrian Foot bridges In Rural Areas*

As mentioned in section 2, five pedestrian footbridges built by Bridges to Prosperity were selected for the assessment. Table 1 summarizes the overall main findings from the interviews, discussions with different surrounding communities, and the observations made during site visits of those five pedestrian footbridges. The table summarizes the effect and overall rating (the magnitude of the effect), the percentage of similarity feedback, and further comments that were considered for assigning each effect with its rating.

Table 2: Results from Interview, Discussions, and Observations

Effect	Positive Overall rating	% Similarity Feedback from Respondents	Situation before the construction of Pedestrian footbridge in the area.
Way of Life (Accessibility and Connectivity)			
Access to schools	Significant Positive	97%	During the rainy season, students were not able to attend the schools. some were not able to go back home and stay at school.
Access to Markets	Significant Positive	98%	During the rainy season, Communities could not attend the local markets and even sometimes they could not back home, until the water in the river get low.
Access to Health/ Hospital center	Significant Positive	96%	During the rainy season, Communities could not go to health centers and hospital due to high water level over the existing log timber bridge.
Access to Church	Significant Positive	94%	The attendance to churches was low during the rainy season. Communities couldn't cross when the river is flooded.
Access to Drinking water	Moderate Positive	95%	Some communities from one side use the bridge to fetch drinking water from the other side of the river.
Access to Public Offices	Moderate Positive	93%	Some communities use the bridge to go the sector and cell offices.
Access to Public Transport	Significant Positive	97%	It was difficult to access the bus station during rainy season, and the bridge made consistent access possible.
Saving Walking/Travel Time	Significant Positive	100%	The alternative safe crossing points are far from the residences and the social-economic facilities. The average distance is about 9km from nearest village to the nearest facility.
Well-being (Health and Safety)			
Saving lives	Significant Positive	98%	Before the bridge was constructed, many people died while crossing the river.
Decrease of injuries	Significant Positive	98%	Before the bridge was constructed, many people were injured while crossing the river.
General improvements to pedestrian and cyclist safety	Moderate Positive	96%	People of all ages were able to cross safely during bridge construction
Reducing infant and maternal mortality	Moderate Positive	94%	Since the health center is far from the alternative safe crossing point, before the bridges, some mothers were insisting on giving birth at home by preventing to cross the river.
Ability to pay the health insurance (Mutuel de Sante)	Significant Positive	92%	The bridges increased the economic revenue, which gave the communities the ability to pay their "mutuel de sante"
Financial (Income and Cost)			
Economic benefit from farming goods	Significant Positive	99%	Pedestrian footbridges allowed farmers to bring their products on their expected local markets, which increased the price.
Additional economic benefits from products and farming goods	Significant Positive	97%	Pedestrian footbridges allowed the farmers to bring all their products to market.
Economic benefits from additional worker jobs	Significant Positive	98%	Pedestrian footbridges allowed the workers to access their daily activities and earn additional income.
Business revenue change	Significant Positive	95%	Pedestrian footbridges increased the traffic flow, therefore the customer flowed to surrounding businesses.

Saving money for travel cost	Significant Positive	99%	Pedestrian footbridges decreased the travel distance for motorcyclists and bicyclists with their passengers.
Reduction of accident cost	Moderate Positive	90%	Accidents were reduced due to the presence of Pedestrian footbridge.
Reduction of operational costs for motorcycles and bicycles	Minor Positive	80%	The cost to repair the motorcycle and bicycles was reduced due to shorter travelling distances.
Reduction of delay cost	Significant Positive	98%	Working hours were increased due to time saving as a result of the shorter travelling and walking distance.
Government tax	Significant Positive	87%	Taxes from agriculture production were increased, as a result of the increases in investments and yields.
Change to Well-being and Cultural well being			
Increased trust between community and government	Significant Positive	96%	The social and cultural coherence and the economic growth, resulted from having Pedestrian footbridge in community rural areas gave them great pleasure and much confidence and appreciation of their leaders.
Interaction and visits of friends and relatives	Significant Positive	99%	Pedestrian footbridges facilitated the communities to visit each one another.
Improvement of crossing way of disability people	Significant Positive	96%	Following Pedestrian footbridge construction, people with disabilities were able to cross the river safely.
Work occupation of local communities	Moderate Positive	94%	Attendance to work increased following Pedestrian footbridge construction.
Decrease of family conflicts	Moderate Positive	90%	Due to work occupation, the conflicts in the family has been decreased.
Increase of school attendance of new students	Minor Positive	94%	Footbridge facilitated the students to attend schools without fail.
Success of students	Moderate Positive	93%	the increase of student attendance, and short walking distance affected the overall student results.

b) Economic Impact Analysis of Pedestrian Footbridge

Cost categories of the economic impact of the pedestrian footbridge are summarized in Figure 1. As shown by the figure, the economic impact was quantified using user cost for motorcycles and bicycles, user cost for pedestrians, economic benefit, and business revenue change. The scope of analysis presented in this study is limited to the duration of one year.

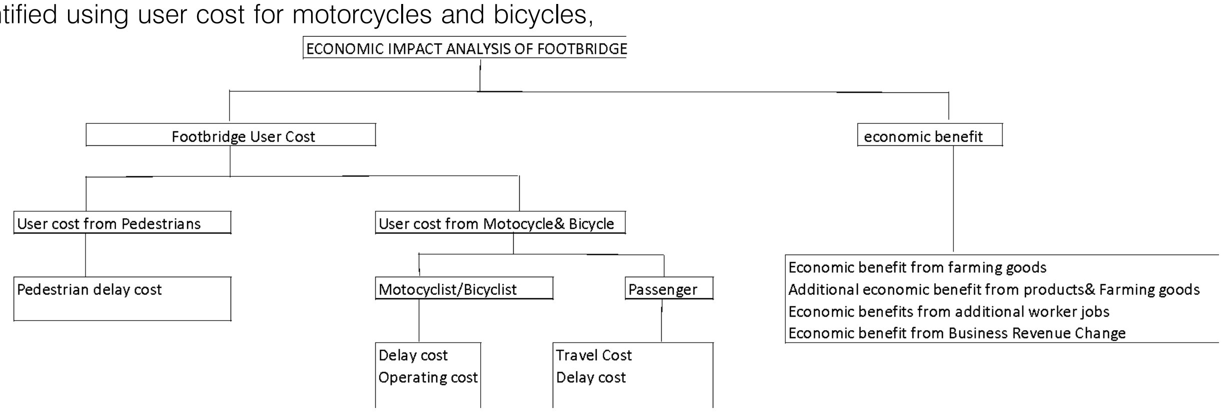

Figure 1: Economic Impact Analysis Pedestrian footbridge

i. *Economic Impact from user Cost*

As shown in Figure 1, the economic impact from User Cost is evaluated from Bicycle/Motorcycle user cost and pedestrian user cost. They include motorcyclist/bicyclist, passenger, and pedestrians' costs. The Motorcyclist/Bicyclist cost is comprised of the travel cost (fuel cost, etc.), the delay cost (the Amount of profit that a motorcyclist or bicyclist loses when they are late to get to their destination), and the Operating cost (Tire or tube replacement, general mechanical repair, etc.). The passenger cost comprises of the delay cost (the Amount of profit that a passenger loses when they are late to get to their destination) and the travel cost (transport charges, etc.). The Pedestrian cost comprises of the delay cost (the Amount of profit that a pedestrian loses when they are late to get to their destination). Equations developed by [15] have been considered, modified, and from there, the following equations 1 to 12 were developed.

Pedestrian Delay Cost is calculated:

$$PDC = (WT_{CAP} - WT_{CB}) * ADT_P * IDY_P * HR_p \quad (1)$$

Where 'WT_{CAP}' is the walking time by crossing the alternate crossing point (the nearest other safe crossing point); 'WT_{CB}' is the walking time by crossing the bridge; 'ADTp' is average daily pedestrian traffic; 'IDY_P' is the impassable days per year for pedestrians (when the river is flooded and not impassable), and 'HR_P' the hourly rate for pedestrians.

The formulas for user cost from Motorcyclist and Bicyclist were developed as follows:

Motorcyclist Travel Cost:

$$MTC = [(TT_{CAPM} - TT_{CBM}) * ADT_M * IDY_M * TR_M)] \quad (2)$$

Motorcyclist delay Cost:

$$MDC = [(TT_{CAPM} - TT_{CBM}) * ADT_M * IDY_M * HR_M)] \quad (3)$$

Bicyclist delay cost:

$$BDC = [(TT_{CAPB} - TT_{CBB}) * ADT_B * IDY_B * HR_B] \quad (4)$$

Motorcycle Operating Cost:

$$MOC = (TT_{CAPM} - TT_{CBM}) * ADT_M * IDY_M * MOC \quad (5)$$

Bicycle Operating Cost:

$$BOC = (TT_{CAPB} - TT_{CBB}) * ADT_B * IDY_B * BOC \quad (6)$$

Motorcycle passenger travel Cost:

$$MPTC = [(TT_{CAPMPS} - TT_{CBMPS}) * ADT_{MPs} * IDY_{MPS} * TR_{MPS}] \quad (7)$$

Motorcycle passenger delay Cost:

$$MPDC = [(TT_{CAPMPS} - TT_{CBMPS}) * ADT_{MPs} * IDY_{MPS} * HR_{MPS}] \quad (8)$$

Bicycle Passenger Travel Cost:

$$BPTC = [(TT_{CAPBPS} - TT_{CBBPS}) * ADT_{BPS} * IDY_{BPS} * TR_{BPS}] \quad (9)$$

Bicycle Passenger delay Cost:

$$BPDC = [(TT_{CAPBPS} - TT_{CBBPS}) * ADT_{BPS} * IDY_{BPS} * HR_{BPS}] \quad (10)$$

where,

Table 3: Abbreviation Definitions

Abbreviation	Definition
ADT_M	Average daily motorcycle traffic
ADT_B	Average daily bicycle traffic
ADT_{BPS}	Average daily bicycle passenger traffic
ADT_{MPS}	Average daily motorcycle passenger traffic;
BOC	Bicycle operating cost
HR_B	Hourly rate for bicycles,
HR_M	Hourly rate for motorcycles
HR_{MPS}	Hourly rate for motorcycle passenger
HR_{BPS}	Hourly rate for bicycle passenger.
IDY_M	Impassable days per year for motorcycle (when the river is flooded and not passable)
IDY_B	Impassable days per year for bicycles (when the river is flooded and not impassable)
IDY_{MPS}	Impassable days per year for motorcycle passenger (when the river is flooded and not impassable)
IDY_{BPS}	Impassable days per year for bicycle passengers (when the river is flooded and not impassable)
MOC	Motorcycle operating cost,
TT_{CAPM}	Motorcycle's traveling time by crossing the alternate crossing point (the nearest other safe crossing point)
TT_{CBM}	Motorcycle's traveling time by crossing the bridge
TR_M	Travel rate for motorcycles
TT_{CAPB}	Bicycle's travel time, incurred by crossing the alternate crossing point (the nearest other safe crossing point)
TT_{CBB}	Bicycle's travel time by crossing the bridge;
TR_B	Travel rate for bicycles
TT_{CAPMPS}	Motorcycle passenger's traveling time by crossing the alternate crossing point (the nearest other safe crossing point);
TT_{CBMPS}	Motorcycle passenger's traveling time by crossing the bridge
TR_{MPS}	Travel rate for motorcycle passenger
TT_{CAPBPS}	Bicycle passenger's traveling time by crossing the alternate crossing point (the nearest other safe crossing point
TT_{CBBPS}	Bicycle passenger's traveling time by crossing the bridge
TR_{BPS}	Travel rate for bicycle passenger;

ii. *Business Revenue Change*

The formulas for business revenue changes resulting from the construction of a new Pedestrian footbridge were developed using the theory created by [14]. The business revenue change when the community gets a safe crossing point is a component of economic impact on surrounding businesses. The business revenue increase (BRC) is directly affected by the increase in customer number (IC). It is also a function of average expenditure per household (AE). The number of weeks per year that could be impossible to cross the river without a bridge when it is flooded (IW) means impassable weeks per year.

$$BRC = IC * AE * IW \quad (11)$$

A significant parameter in the quantification of revenue change of a Pedestrian footbridge is the influence area. In this study, the bridge influence area was estimated based on the study conducted by Bridges to Prosperity, as denoted in section 1 above, which was resulted in an average of 17 villages directly served by a single Pedestrian footbridge.

The increase in a number of customers, as shown in Eq. 17, is a function of number of households that would not be able to cross without the bridge when the river is flooded (HCWB) and the percentage area influenced by the bridge (I), and the average frequency per week of patronizing businesses in area (F).

$$IC = HCWB * I * F \quad (12)$$

I and F are estimated using survey data or just by estimating.

c) *Estimation of Economic Benefit Per Year Per Pedestrian Footbridge for Gashyushya Suspension Bridge Case Study*

i. *Gashyushya Trail Bridge Profile*

The Gashyushya pedestrian footbridge is a suspension bridge built in 2019 by a non-Government organization, Bridges to Prosperity, in collaboration with the Muhanga district. The communities surrounding the Gashyushya pedestrian footbridge are primarily occupied by Agriculture of different crops mainly, potatoes and bananas. For accessing their market, they must cross the Makurungwe River. Community members also have to cross the river to access their social-economic facilities like schools, medical care, and jobs.

During the rainy season, the Makurungwe river frequently becomes violent and stays flooded and fast for three days at a time. So, before the construction of the Gashyushya pedestrian footbridge, it was too dangerous to cross during such period, which resulted in innumerable missed opportunities and has caused multiple injuries in attempted crossings and in at least one reported death per year. The Gashyushya pedestrian footbridge provides safe, year-round access for over 3,000 members of the Murama, Munini, and surrounding communities, providing enhanced access to opportunity to empower the communities out of poverty.

Figure 2: Community crossing the river (Before the construction of Gashyushya Pedestrian footbridge)

Figure 3: Community crossing the Gashyushya Pedestrian footbridge

ii. *Economic Impact from Pedestrian Footbridge user Cost*

Tables 2 and 3 summarize the results of the economic impact from the Gashyushya Suspension Bridge constructed in Muhanga District in terms of user cost. Most of the data were estimated from the participants' feedback during the interview and discussion, in addition to the observations made during the site visit. The average daily traffic for pedestrians (ADT_P), the average daily traffic for motorcycles (ADT_M), and the average daily traffic for bicycles (ADT_B) were estimated from the traffic count survey during seven days.

Table 4: Estimated Values for User Cost Parameters

Parameter	Value		Parameter	Value
ADT_B	82 bicycle/day		IDY_P	112 days
ADT_{BPS}	16 passengers/day		TR_M	900 Rwf
ADT_M	53 Moto/day		TR_{MPS}	2,000 Rwf
ADT_{MPS}	32 passengers/day		TT_{CAPB}	0.75h
ADT_P	664 people/day		TT_{CAPBPS}	0.8h
HOC_B	200 Rwf		TT_{CAPM}	0.25h
HOC_M	400 Rwf		TT_{CAPMPS}	0.25h
HR_{BPS}	350 Rwf		TT_{CBBPS}	0.3h
HR_M	500 Rwf		TT_{CBM}	0.05h
HR_P	660 Rwf		TT_{CBMPS}	0.05h
HR_{MPS}	350Rwf		WT_{CAP}	2.0 h
IDY_M	112 days		WT_{CB}	0.3h
IDY_{MPS}	112days			

Table 5: Total user Cost

Parameter's Name	Parameter's Abbreviation	Value (RWF)	Equation used
Bicyclist delay cost	BDC	1,974,560	Equ. 4
Bicycle operating cost	BOC	918,400	Equ. 6
Bicycle passenger delay cost	BPDC	313,600	Equ.10
Bicycle passenger travel cost	BPTC	358,400	Equ. 9
Motorcyclist delay cost	MDC	593,600	Equ. 3
Motorcycle operating cost	MOC	474,880	Equ. 5
Motorcycle passenger delay cost	MPDC	250,880	Equ. 8
Motorcycle passenger travel cost	MPTC	1,433,600	Equ. 7
Motorcyclist travel cost	MTC	1,068,480	Equ. 2
Pedestrian delay cost	PDC	57,652,000	Equ. 1
Total user cost	**TISC**	**57,652,000**	

iii. *Economic Benefit*

The approach used by Rotary International for analyzing the economic benefit for their funded projects was used in this study. It is composed of three main types of benefits, which are the economic benefit from farming goods, the additional economic benefit for products and farming goods, and the economic benefit from additional worker jobs. Table 4 summarizes the results from the Gashyushya Suspension Bridge analysis. The estimated values were from the discussion with local communities and the observations during site visits.

Table 6: Estimate of economic benefit per year per Pedestrian footbridge

Parameter' name	Parameter's Symbole	Value	Equation
Estimated number of bridge users crossing per day (A): **people/day**	A	664	N.E
Estimated number of kilos of farming goods crossing per day(B): **kilos/day**	B	9,960	N.E
Estimated differential sales price between selling product on one side versus newly accessed side(C): **Rwf/kilo**	C	15	N.E
Estimated additional kilos of products/farming goods not otherwise sold without access to other side per annum(D): **kilos/annum.**	D	25,550	N.E
Average price of products sold per kilo(E) **Rwf/kilo**	E	250	N.E
Estimated number of worker crossings per day that would otherwise not be able to access job on newly accessed side(F): **Number**	F	26	N.E
Estimated wages earned by workers per day that would otherwise not be able to gain access to jobs without bridge(G) **RWf /day**	G	1,500	N.E
Number of days that footbridge is used per year by farmers and workers(H): **days**	H	325	N.E
Economic benefit from farming goods(I). **Rwf /day** (Multiply B by C)	I	149,400	(B*C)
Additional economic benefit for products and farming goods(J). **Rwf /day** (Multiply D by E then divide by 365)	J	17,500	[(D*E)/365]
Economic benefit from additional worker jobs(K): **Rwf /day** (Multiply F by G)	K	39,000	(F*G)
Total economic benefit for farming goods and workers(L): **Rwf /day** (Add I + J + K)	L	205,900	(I+J+K)
Estimated economic benefit per year for this footbridge: **Rwf /annum** (Multiply L by H)	M	**66,917,500**	(L*H)

iv. *Business Revenue Change*

As said earlier in this section, the business revenue changes when a community receives a safe crossing point is a component of economic impact on surrounding businesses. The business revenue increase (BRC) is directly affected by the increase in customer number (IC). It is also a function of average expenditure per household (AE). The number of weeks per year that could be impossible to cross the river without a bridge when it is flooded (IW) means impassable weeks per year. Table 5 below summarize the results from the interviews and observations during the site visit of the Gashyushya suspension bridge.

Table 7: Business revenue Increase per year per Pedestrian footbridge

Parameter's name	Parameter's Abbreviation	Value	Equation
number of households that would not be able to cross without the bridge when the river is flooded (Households)	HCWB	2000	
percentage area influenced by the bridge (percentage)	I	50%	
average frequency per week of patronizing businesses in the area (visit per week)	F	2	
average expenditure per household (Rwf/visit/household)	AE	700	
Impassable weeks per year (Weeks/year)	IW	16	
number of customers	IC	2000	(WCWB*I*F)
The business revenue increase (Rwf)	BRC	**22,400,000**	(IC*AE*IW)

d) *Total Economic Benefit Per Year Per Pedestrian Footbridge.*

The total economic benefit from a constructed pedestrian footbridge is the summation of benefit from bridge user cost, farming goods, increase of employment, and the business revenue change. Table 6 summarizes the results of the Gashyushya Suspension Bridge.

Table 8: Total economic benefit per year per Pedestrian footbridge

Benefit Description	Symbol	Amount (Rwf)	Percentage of the Total Benefit
Total user cost per year	UC	57,652,000	39.22%
Economic benefit from farming goods and increase of employment per year	EB	66,917,000	45.53%
Business revenue increase per year.	BR	22,400,000	15.25%
Total economic benefit per year for Gashyushya Suspension Footbridge	FB	**146,969,000**	**100%**

e) Political Satisfaction Effect of Pedestrian Footbridge In Rural Areas

Out of the total population interviewed, 96% showed that having a pedestrian footbridge in their rural areas gave them great pleasure and much confidence and appreciation of their leaders. Pedestrian footbridge increased the benefit from gross domestic products, which changed the economic situation in rural areas. Pedestrian footbridges increased the economic prosperity of a rural communities. Pedestrian footbridge in the traditional footpaths helps rural communities not only to access the social-economic facilities but also motivate and increase community hope and efforts, which affect the trustworthiness of the government to prioritize the population.

f) Discussion

i. *Results Validation*

The results from interviews and discussion are presented in Table 1. About 90% of participants were pedestrian footbridge beneficiaries in one way or another. These included the bridge users who cross it regularly to access their social-economic facilities, as well as others whose lives improved as a result of the overall economic benefit and business revenue change due to the pedestrian footbridges in their areas. There are some others who made and who are making money from the construction and use of pedestrian footbridge in their rural areas, where we can say for example the motorcyclists and cyclists.

The formulas to estimate the economic benefit year per pedestrian footbridge were developed from international theories for estimating the economic benefit for infrastructure projects. It was based on the existing factors that influence the economic growth in rural areas. The price of each factor was estimated from the information given by the local communities surrounding the pedestrian footbridge in the study.

ii. *Discussion of the Results*

Social-Economic Effects of Pedestrian footbridge in Rural Areas:

1) More than 97% of respondents confirmed that pedestrian footbridges in their rural areas were effectively changing their livelihoods both socially and financially [5]. This is understandable because pedestrian footbridge improves their accessibility to social-economic facilities like schools, markets, health centers, etc. During the rainy season, the river was impassable, and many activities were stopped until the water lowered.
2) What was also found is that pedestrian footbridge is not only beneficial to the surrounding communities but also to the wider communities [7]. During the site visit on market day, some communities attending the market indicated that people traveled from 10 – 15 kilometers away (two to three hours walking). This is mainly caused by the small number of social-economic facilities presented in some rural areas.
3) Gashyushya Suspension Bridge built by Bridges to Prosperity was taken as a case study to analyze the economic benefit per year. The total benefit resulting from bridge user cost represented about 39.22% of the total benefit of the bridge per annual. The Benefit from the farming goods and products in addition to the benefit from additional work jobs takes about 45.53 %, while the benefit from the business revenue changes represents about 15.25 %.
4) It has been found that in some areas, communities do not benefit from the constructed pedestrian footbridge due to the small number of bridges presented in the area, because there are need for pedestrian footbridges, but they are not known. There should be a better way to identify all needed pedestrian footbridges in rural areas [8]. Otherwise, some communities are having difficulties to cross a water point before they access the constructed Pedestrian footbridge.

Political Satisfaction Effects of Pedestrian footbridge in Rural Areas:

1) Pedestrian footbridge increased the government trustworthiness of the communities around the constructed pedestrian footbridge in rural areas. This is very understandable because one of the indicators of the political satisfaction of the population are the social and cultural coherence and economic growth, which are directly affected by infrastructure development
2) Pedestrian footbridges helped the communities not only to access their social-economic facilities but also to fulfill their needs and desire and increased

the benefit from gross domestic products, which increased the economic prosperity in their rural areas.

IV. Conclusion

The main objective of this study was to identify potential benefits and propose the comprehensive approach of estimating the economic benefits of a pedestrian footbridge in rural areas to better understand the potential impacts of the constructed pedestrian footbridges in rural areas and the likely responses of those impacted by the projects. With the detailed literature review, interviews, and discussion with different foot bridging stakeholders, the following results were achieved:

1. As per the majority of participants in this study, a pedestrian footbridge in rural areas have a significant social-economic effect which are directly affect the political satisfaction of local communities in rural areas.
2. Different formulas were developed, and one bridge was selected as a case study to analyze its economic benefit to the surrounding community. The total benefit resulted from the user cost, farming goods, and products, and benefit from the business revenue was estimated as One hundred and forty-six million and nine hundred and sixty-nine thousand Rwandan Francs (146,969,000 Rwf) per year. This number is a good example and proof of investment needs in the pedestrian footbridges, which affect not only the rural community but also the country's economy in general.
3. The present detailed bridge social-economic effects, which are conducted by Bridges to Prosperity before and after the bridge is built, could help to understand how communities are being impacted by pedestrian footbridges in rural areas.
4. All Pedestrian footbridge effects outlined in this study were adequate and comprehensive enough to support relevant authorities to prioritize the pedestrian footbridges wherever they are needed in the country.

Based on the above results, it is recommended that pedestrian footbridges could be prioritized not only to provide access to the rural communities but also to facilitate their economic growth to break the cycle of poverty. A further study would be welcome for a comparative investigation between the total cost of a new pedestrian footbridge with the total economic benefit of a pedestrian footbridge during its entire life span, to understand well how the investment in pedestrian footbridge can contribute to the entire economic growth of a country.

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References Références Referencias

1. National Cooperative Highway Research Program, "Assessing the Social and Economic Effects of Transportation Projects," Boston, Massachusetts , 2001.
2. W. B. Prosperity.org, "Government of Rwanda and B2P signed a memorandum of Understanding to built 354 bridges in 5 years," 2019.
3. N. Achjar and M. A. Panennungi, "The Impact of Rural Infrastructure Development on poverty Reduction in Indonesia," 2010.
4. R. J. Burdge, "Impact Assessment and Project Appraisal," 2003.
5. K. Matthews, How Building Footbridges can improve Rural Economies, 2017.
6. W. D. o. Transportation, "Guidance for Conducting an Indirect Effects Analysis," Environmental Policy and Community Impacts Analysis Section, Bureau of Equity and Environmental Services (BEES), Division of Transportation System Development (DTSD), , 2015.
7. N. Abbie, B. Oliver and C. Barstow., "Trailbridges May Have A Far Broader Impact Than Once Thought," Engineering for Change, September, 2020.
8. Kyle Shirley; Abbie Noriega; Davey Levin; and Christina Barstow, "Identifying Water Crossings in Rural Liberia and Rwanda Using Remote and Field-Based Methods," Multidisciplinary Digital Publishing Institute (MDPI), 2021.
9. Munyaneza C.; Mbereyaho L., "Development of A Comprehensive Pedestrian Footbridge Management System," Journal of Civil Engineering, Science and Technology, 2020.
10. W. Brooks and K. Donovan, Eliminating Uncertainty in Market Access: The Impact of New Bridges in Rural Nicaragua, University of Notre Dame, 2020.
11. S. Handy, S. Kubly, D. Larsen, J. Sralla, S. Vanka and a. M. Oden, "Economic Effects of Highway Relief Routes on Small-and Medium-Size Communities: Case Studies," Center for Transportation Research- Bureau of the Engineering Research- The University of Texas at Austin , Texas, 2001.
12. J. K. Duvsjö, "What is affecting political trust?," Linnaeus University-Department of Political Science, 2014.
13. F. Vanclay, A. M. Esteves, I. Aucamp and D. M. Franks, "Social Impact Assessment: Guidance for

Assessing and Managing the Social Impacts of Projects," International Association For Impacts Assessment (IAIA), 2015.

14. F. Yavuz, "ECONOMIC IMPACT ANALYSIS OF BRIDGE CONSTRUCTION," Department of Civil and Construction Engineering, Western Michigan University, Western Michigan , 2017.
15. M. A. E. a. H. E. Marchall, The economic of New-Technology Materials: A case study of FRP Bridge decking, Gaitherburg: Building and Fire Research Laboratory, July, 1996.

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A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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