Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

Kaizen in electronic and photovoltaic manufacturing and its effects on productivity and operating costs.

Kaizen in electronics and photovoltaic manufacturing and its effects on productivity and operating costs

Kaizen in electronics and photovoltaic manufacturing and its effects on productivity and operational costs

Felipe Thomaz Souza Perri1
Electrical Engineer from the Faculty of Engineering of Sorocaba (FACENS, 2015). MBA in Maintenance and Production Management from FACENS (2020). MBA in Industrial Management, Logistics and Quality from Faculdade Líbano (2026). Currently pursuing an Executive MBA in Competitive Management and Business Intelligence from Faculdade Líbano. Certified Six Sigma Green Belt / Lean Green Belt.

SUMMARY

Continuous improvement based on the Kaizen principle is traditionally associated with low-cost incremental gains, but quantified evidence of its application in electronic manufacturing test lines and photovoltaic module manufacturing processes in Brazil is still scarce.
This article analyzes three Kaizen projects conducted between 2016 and 2021 at a contract electronics manufacturing unit located in Sorocaba, São Paulo state, two of them in computer testing lines and one in the photovoltaic module lamination process.
A retrospective multiple case study approach was adopted, with the author as a participant, and data were extracted from project closure records. Results indicate productivity increases of 58%, 22%, and 30%, a 92% reduction in defects attributed to lamination revenue parameters, and estimated annual savings of approximately US$2.78 million across all cases. Cross-analysis suggests that the greatest gains resulted from revising work content and testing logic, not from acquiring new equipment, and that the multidisciplinary composition of the teams and the disciplined use of the PDCA cycle were key to the results. Factors associated with sustaining these gains, the effects on working conditions, and the complementarity between Kaizen and Industry 4.0 technologies are also discussed.

Keywords: Kaizen; continuous improvement; lean manufacturing; electronic manufacturing; photovoltaic modules.

ABSTRACT

Kaizen-based continuous improvement is traditionally associated with low-cost incremental gains, yet quantified evidence of its application to electronics manufacturing test lines and to photovoltaic module production in Brazil remains scarce. This article analyzes three Kaizen projects carried out between 2016 and 2021 at an electronics manufacturing services plant located in Sorocaba, São Paulo State, two of them on computer test lines and one in the photovoltaic module lamination process. A retrospective multiple case study design was adopted, with the author acting as a participant, and data were drawn from the projects' closing records. Results show productivity increases of 58%, 22% and 30%, a 92% reduction in defects attributed to lamination recipe parameters, and estimated annual savings of approximately US$ 2.78 million across the cases. The cross-case analysis suggests that the largest gains came from

1Electrical Engineer from the Faculty of Engineering of Sorocaba (FACENS, 2015). MBA in Maintenance and Production Management from FACENS (2020). MBA in Industrial Management, Logistics and Quality from Faculdade Líbano (2026). Currently pursuing an Executive MBA in Competitive Management and Business Intelligence from Faculdade Líbano. Certified Six Sigma Green Belt / Lean Green Belt. Engineer registered with CREA-SP and member of the Brazilian Association of Engineering Education (ABENGE).

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

redesigning work content and test logic rather than from acquiring new equipment, and that multidisciplinary team composition and the disciplined use of the PDCA cycle were decisive for the results. The article also discusses the factors associated with sustaining the gains, the effects on working conditions, and the complementarity between Kaizen and Industry 4.0 technologies.

Keywords: Kaizen; continuous improvement; lean manufacturing; electronics manufacturing; photovoltaic modules.

1 INTRODUCTION

The manufacturing industry today operates under a combination of pressures that rarely occur.
They simultaneously present, with compressed margins, product life cycles each.
shorter timeframes, increasing quality demands, and a shortage of qualified professionals.
to conduct operations and maintenance. In this environment, the pursuit of productivity is common.
decisions can be associated with the acquisition of more modern equipment or extensive automation.
which require capital and a maturation period. The tradition of continuous improvement offers a path.
complementary and less expensive. Since Imai (1986) introduced Kaizen to the public.
Westernization was seen as the key to Japanese competitive success, solidifying the idea that the accumulation of knowledge was the key to Japanese competitive success.
Disciplined implementation of small changes, driven by the teams themselves, can produce results.
economics comparable to those of large-scale investments. Bhuiyan and Baghel (2005)
They show that this premise runs through virtually all approaches to continuous improvement.
emerging throughout the 20th century, from suggestion systems to the combination of manufacturing
Lean and Six Sigma.
Despite the extensive literature on the subject, significant gaps remain. Empirical studies
more robust approaches to Kaizen events, such as those by Farris et al. (2009), Van Aken et al. (2010) and
Glover et al. (2011) focus on North American organizations and prioritize analysis.
of the critical success factors and the outcomes for people, with less emphasis on
Financial quantification of specific projects. In Brazil, Godinho Filho and Fernandes (2004)
They proposed a classification of works on lean manufacturing and pointed out perspectives.
for future research, and Tortorella and Fettermann (2018) investigated the relationship between practices
Lean manufacturing and Industry 4.0 in Brazilian companies. However, reports on these are still infrequent.
which document, with productivity, quality and cost figures, the application of Kaizen.
in electronic manufacturing test lines under contract and in module fabrication.
photovoltaics, two segments of high technological intensity and growing relevance for
the national economy.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

Given this, the objective of this article is to analyze three Kaizen projects conducted between 2016 and 2021 at a contract electronics manufacturing facility located in Sorocaba, in the state from São Paulo, identifying the nature of the interventions carried out, the tools used, The text describes the results obtained and the factors that contributed to those results. organized into nine sections. After this introduction, the second section describes the route. methodological. Sections three through five discuss the conceptual foundations of Kaizen, its Integration into the lean manufacturing and Six Sigma systems and the most advanced analytical tools. relevant to the reality of the test lines. Sections six and seven present the cases studied, The eighth section performs a cross-analysis of the results and discusses their rationale, and the ninth section brings together the... conclusions, limitations, and suggestions for future studies.

2 METHODOLOGY

This research is characterized as applied in its purpose, and exploratory and descriptive in its approach. to the objectives and combined approach, since it articulates the qualitative interpretation of Interventions using quantitative performance indicator analysis. The design The multiple case study approach adopted was the one recommended by Yin (2018) when the researcher seeks to understand contemporary phenomena in their real context, about which it has little knowledge. or no experimental control, and when the boundaries between phenomenon and context are not clearly defined. Voss, Tsikriktsis and Frohlich (2002) add that research based In some cases, it is particularly suitable for operations management as it allows for the examination of practices. in its organizational complexity, without the need to reduce the object to variables. isolated, which corresponds to the nature of the continuous improvement projects analyzed here. The empirical context is a manufacturing plant of a multinational manufacturing company. Contract electronics, a segment known internationally as Electronics Manufacturing Services, which during the period studied served, among other clients, a manufacturer. A global manufacturer of personal computers and a manufacturer of photovoltaic modules. Between 2016 and 2021, The author participated in eleven Kaizen projects at this unit, focused on reducing waste, and... increased yield, reduced defects in rolling mills, and reduced downtime. equipment. For this study, three projects were selected according to two criteria. cumulative, the existence of financial results recorded at closing and the performance of The author was chosen as the team leader or co-leader. The selection followed the logic of literal replication described.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

by Yin (2018), in which similar cases are chosen to verify if observed patterns
In one of them, the same patterns are repeated in the others.

The sources of evidence were project closure records and indicators of productivity, performance, and defects are monitored by the teams, along with the procedures. Operational guidelines developed during interventions and technical documentation for the equipment. involved. As the author participated directly in the initiatives, the research retains proximity to action research in operations management discussed by Coughlan and Coghlan (2002), which highlight both the value of the researcher's prior knowledge of the system studied regarding the risk of interpretation biases arising from this involvement. To mitigate Given this risk, the analysis was limited to the data formally consolidated at the end of each project. without the addition of subsequent estimates, and the interpretations were compared with the literature whenever possible, in order to separate what the records demonstrate from what the
The author's experience suggests this.

The analysis was conducted in two stages. In the first, each case was described individually. According to five analytical categories, the problem that motivated the project, the nature of intervention, the tools used, the results recorded, and the mechanisms adopted for sustain the gains. In the second, the cases were compared to each other, a procedure that Yin (2018) calls it cross-synthesis, in order to identify regularities and differences. Two Limitations should be explicitly stated from the outset. The savings figures are estimates. annualized values recorded at the end of the projects, according to internal criteria of organization, and were not subject to independent audit. Furthermore, the indicator of Productivity followed the internal definition adopted for each line, which prevents comparison. Directly between the percentages. Out of respect for confidentiality, the company and its clients are not... identified by name.

3 CONCEPTUAL FOUNDATIONS OF KAIZEN AND CONTINUOUS IMPROVEMENT

The term kaizen, which in Japanese means gradual and continuous improvement, gained traction in The West, based on the work of Imai (1986), presented it as the unifying principle of Management practices responsible for the competitive rise of Japanese industry in the post-war period. According to the author, Kaizen differs from innovation in that it depends less on large investments. in technology and more from the systematic involvement of people in identification and elimination. of everyday problems. This distinction does not imply opposition between the two approaches. Imai

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

(1986) argues that innovation produces leaps in performance that tend to deteriorate.
when they are not accompanied by a permanent effort to maintain and improve them
New standards, and it is precisely this effort that Kaizen organizes. Continuous improvement,
Therefore, it does not replace investment, but creates the conditions for it to produce a return.
expected, so that the new level of performance is not lost over time.
In later work, Imai (1997) shifts the emphasis to gemba, a term that designates the place.
where value is effectively created, such as the production line or the testing station. The argument
The key point is that operational problems must be understood where they occur, starting from...
direct observation, and that the lowest-cost solutions often emerge from those who execute the work.
work. The author associates this perspective with three basic activities: standardization,
Organizing the work environment through the 5S methodology and the systematic elimination of waste.
Standardization plays a unique role here, as it serves as a baseline from which
Every improvement is measured and, once validated, incorporated. Without a stable standard, there's no way around it.
distinguishing a genuine improvement from a random fluctuation in the process is what makes the discipline of
Measurement is an inseparable component of the Kaizen philosophy itself, not an accessory.
methodological.
Academic literature has begun to treat continuous improvement not only as a set of
not just techniques, but organizational capabilities that develop over time. Bessant,
Caffyn and Gallagher (2001) proposed an evolutionary model with five levels of maturity,
ranging from an initial and sporadic interest in improvement to the status of an organization capable of
Learning systematically from one's own experiences. For these authors, the
Advancement between levels depends on the consolidation of specific behavioral routines, such as
ability to link local improvements to the company's strategic goals and the capacity to
to share learning across areas. The model's main contribution is to show
that isolated impressive results do not equate to a culture of improvement, and that repetition
Successful projects require support structures that extend beyond the scope of each individual project.
individual initiative.

Bhuiyan and Baghel (2005) reconstruct the historical trajectory of improvement approaches.
continuous, from the suggestion systems of the early 20th century to the combination
contemporary relationship between lean manufacturing and Six Sigma. The authors note that the different
methodologies share the premise that small incremental changes, when
Accumulated and sustained factors produce significant effects on quality, cost, and deadlines, but
They differ in terms of the degree of statistical formalization and the form of involvement of

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

workers. This historical reading is useful because it dispels the idea that Kaizen was a
An isolated or culturally non-transferable technique. Rather, it is a family of practices that
They converge on the same management principle, which is that the performance of a system
Productivity can be continuously increased through disciplined investigation of its losses and by
Incorporating learning into the work pattern.

The methodological core of this investigation is the cycle of planning, executing, verifying, and acting.
known by the acronym PDCA. Moen and Norman (2010) show that the cycle originates from
The specification, production, and inspection model formulated by Shewhart was reintroduced by
Deming spoke to Japanese engineers in 1950 and, from then on, it received different formalizations.
including the PDSA version, in which the verification stage is replaced by the study of the results.
Deming (1986) argued that improving the system is the responsibility of management and that the greatest
Part of the quality problems stem from the system itself, and not from the individual conduct of the...
operators. The practical implication for Kaizen is straightforward. An improvement project that does not
It explicitly states the hypothesis to be tested, but does not measure its effect and does not incorporate the learning into the standard.
The work process replicates the cycle's form without fulfilling its function.

4. KAIZEN IN THE LEAN MANUFACTURING AND SIX SIGMA SYSTEM

The international spread of Kaizen is closely linked to that of the Toyota Production System.
Ohno (1988) describes this system as a permanent effort to reduce the interval between
The customer's order and receipt of payment, obtained by eliminating everything that is not...
adds value. The author classified the losses into seven categories: overproduction, waiting,
transportation, unnecessary processing, inventory, unnecessary movement and
production of defective items, and attributed particular gravity to overproduction because it concealed the
Furthermore, according to Ohno (1988), the pillars of just-in-time and autonomation would not be sufficient
without the participation of workers in the continuous identification of these losses. It is at this point...
Kaizen ceases to be a parallel program and becomes integrated into the very logic of
functioning of the system, as a mechanism for permanent adjustment between the current standard and the
Actual operating conditions.

The term lean production was coined by Krafcik (1988) when comparing the performance of
car manufacturers from different regions of the world, and gained prominence with the study of
International Motor Vehicle Program reported by Womack, Jones and Roos (1990). Holweg
(2007), in reconstructing the genealogy of the concept, shows that it resulted from a process of

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

progressive abstraction, in which practices developed in a specific context were
translated into principles considered transferable to other sectors. Womack and Jones (1996)
They synthesized these principles into five steps: specifying the value, identifying the flow.
Value creation, continuous flow, pull production, and the pursuit of perfection. The last of these.
In practice, this corresponds to Kaizen, understood as the mechanism that prevents the system from becoming...
to accommodate a new level of performance and that keeps the elimination agenda open.
losses even after initial targets have been reached.
From an empirical standpoint, Shah and Ward (2003) demonstrated that lean practices tend
to be adopted in four interrelated sets, aimed at just-in-time production, to
total quality management, total productive maintenance and human resources management, and that
The effect on operational performance is greater when these sets are implemented.
in a combined way. The study also indicated that plant size and other variables of
Context influences the likelihood of adoption. Spear and Bowen (1999) offer a
An epistemological explanation for the success of the Toyota system, according to which each
Activity, connection, and flow are designed as a testable hypothesis, so that any
The deviation is quickly noticed and addressed according to the scientific method. This reading brings the...
Kaizen is an experimental procedure incorporated into routine, not a sporadic event.
team mobilization.
Six Sigma, in turn, introduced a more formal layer to continuous improvement.
Statistical treatment of variation. Schroeder et al. (2008) define the approach as a
an organized structure running parallel to the functional hierarchy, supported by specialists in
improvement, in a structured problem-solving method and in performance metrics,
with the aim of reducing process variation. Linderman et al. (2003) examined the Six
Sigma in light of goal-setting theory and argued that the combination of goals
Specific and challenging tasks with an explicit research method promote performance.
from the improvement teams. The two contributions help to understand why, in many
In organizations, Kaizen and Six Sigma coexist without conflict. The former mobilizes the
tacit knowledge of the factory floor, while the second offers analytical rigor for the
problems whose cause is not visible to direct observation.
The integration between these approaches is especially relevant in electronic manufacturing, where
Flow losses, typical of the lean domain, coexist with variation losses, typical of the lean domain.
statistician. Shingo (1989) already warned that improving individual operations does little to alter the
Overall performance depends on the process not being understood as a whole, and it established the distinction.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

between process analysis, which tracks the flow of material, and operation analysis, which
It accompanies the work of people and machines. Liker (2004) reinforces that tasks
Standardized practices form the basis for continuous improvement and employee engagement.
In Brazil, the review by Godinho Filho and Fernandes (2004) organized the academic production on
Lean manufacturing was categorized and indicated avenues for future research, an agenda to which the
This study seeks to contribute by gathering evidence from the electrical and electronic segments.
photovoltaic.

5 ANALYTICAL TOOLS AND THE LOGIC OF THE BOTTLENECK IN PRODUCTION LINES TEST

Value stream mapping, as proposed by Rother and Shook (1998), has become the point of
The most widespread approach for improvement projects in production lines. The technique consists of...
to represent the current state of the flow of materials and information, to identify the steps that are not
They add value and design a future state in which the flow is more continuous and driven by...
demand. A central concept of this method is takt time, obtained by dividing time
Available production based on customer demand during the same period. The comparison between the takt
The time and cycle time of each station immediately reveals which stages are incompatible with
The demand, and therefore where improvement efforts should focus. In test lines,
This comparison is often revealing, because the functional testing period tends to be long.
and is not very flexible, and because the allocation of operators often follows the quantity
of stations and not the actual content of the work.
Bottleneck logic adds a systemic dimension to this analysis. Goldratt and Cox (1984)
They popularized the idea that the performance of a production system is limited by its
restriction, so that an hour lost at the bottleneck is an hour lost for the entire system.
while improvements to non-restrictive features may only produce the appearance of
progress. Hopp and Spearman (2008) gave this intuition formal treatment, relying on
Little's law, demonstrated by Little (1961), states that the work-in-process inventory is equal to
The product of the output rate and the throughput time. The practical consequence is that the increase
Capacity at the bottleneck increases the system's output rate without a proportional increase in inventory.
in process, whereas the indiscriminate release of material for a restricted line only
It lengthens queues and increases throughput time, without any gain in production.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

A diagnostic study conducted by the author on an electronics assembly line illustrates... The usefulness of these tools together. The line had an approximate capacity of 735 plates per day against a projected demand of 1,200 plates per day, which meant meeting approximately 61% of the need required a capacity increase of around 63%. to balance supply and demand. The diagnosis combined value stream mapping, the Spaghetti diagram for visualizing the movement of people and materials, the comparison between takt time and cycle time, Pareto and Ishikawa diagrams, 5S and work standardized. The value of this exercise lies not only in identifying the bottleneck, but in... demonstration that the gap between capacity and demand is rarely explained by a single cause, which justifies combining flow tools with analysis tools. of causes.

Among the tools for analyzing causes are the Pareto diagram and the cause-and-effect diagram. They occupy a central position. Juran and Godfrey (1999) consolidated the Pareto principle as prioritization criterion, by showing that, in most processes, a reduced number of Causes account for the majority of losses, allowing resources to be concentrated where the return is highest. is greater. Ishikawa (1985), in turn, argued that most quality problems This can be solved using basic statistical tools, provided they are applied correctly. disciplined and by people from all levels of the organization. The cause-and-effect diagram, which It bears his name, organizing the hypotheses into families such as method, machine, material, manpower. work, measurement and environment, and transforms the discussion of a complex problem into a a set of objective checks, which is particularly useful when teams from different The different areas need to reach a common diagnosis.

When causes interact with each other or when the risk of failure needs to be anticipated, More formalized tools become necessary. The analysis of modes and effects of failure, described by Stamatis (2003), prioritizes risks based on the combination of severity, occurrence and detection, and allows a team to identify the points in place before deployment. that a new process or piece of equipment may fail. The planning of experiments, systematized by Montgomery (2013), it allows for the simultaneous investigation of the effect of various factors and their interactions on a response variable, with a reduced number of trials.

In the experience reported in this study, these two tools were used in the acceptance of an automated screwdriving station, a situation in which the sequence and parameters of The tightening process needed to be validated before release for production, demonstrating that Kaizen It does not dispense with statistical rigor when the nature of the problem demands it.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

6. RESTRUCTURING TEST LINES IN ELECTRONIC MANUFACTURING

In contract electronics manufacturing, the testing phases serve the purpose of ensuring that each assembled board, each integrated device, and each packaged unit meets the Customer specifications prior to shipment. In the unit studied, the computer lines These included testing of assembled boards, testing of the complete equipment, and final verification at the facility. Packaging. The author worked in test engineering, with responsibility for analysis. statistical analysis of station performance, fault investigation, preparation and Configuring stations for new product launches and through the technical interface with the customers. This position allowed them to observe that a significant portion of the stations' cycle time was not It corresponded not only to the execution of the test itself, but also to stages of preparation, waiting and manual intervention, losses that Ohno (1988) would classify as waiting and processing. unnecessary and tend to go unnoticed when the analysis is limited to the time frame of machine.

The first case, referred to here as Case A, consisted of restructuring the testing line of Desktop computers from a global manufacturer, conducted using the Kaizen methodology under The author's leadership. The team analyzed the production process and altered the test schedule. functional to eliminate steps that required operator intervention and automated part of the manual operations. The most visible effect was the change in the relationship between people and equipment, since a single operator was now operating two pieces of testing equipment, which This reduced the need for labor in this phase. Closing records indicate an increase. a 58% increase in productivity and an estimated annual savings of approximately US$1.24 million. The result is consistent with Shingo's (1989) distinction between human labor and the work of machine, according to which the operator should not remain idle while the equipment is in operation. It executes an automatic cycle.

Case B dealt with the notebook testing line for the same client, a project in which the author participated. as co-leader. The focus was on eliminating waste and streamlining operations. with a reduction in the number of operators needed. The productivity increase recorded The increase was 22%, and the estimated annual savings reached approximately US$1.1 million. The difference between The percentages for Cases A and B should not be interpreted as indicating lower effectiveness of the second. project. The available records do not allow for a breakdown of the factors that explain this. There is a difference, but it is plausible that the lines started from different initial conditions regarding the degree. automation and the content of manual work would reduce the scope for improvement.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

available. This caution is consistent with Shah and Ward's (2003) warning that the context
The characteristics of each plant influence the effects of lean practices.

Alongside the two projects, the author led the development of local testing stations.
with the purpose of reducing costs, increasing productivity, and streamlining maintenance.
Internal and external maintenance, and to reduce the cost of spare parts. The solutions were designed to...
Maintain 100% test coverage of the units, including automatic recording of results.
and improvements in quality indicators. In an initiative related to the implementation of control
of the test kits, a second analysis stage of the rejected parts, and a procedure
Formal rework reduced the maintenance cost of parts used in testing by 75%.
This result illustrates Imai's (1997) argument that lower-cost improvements
They often result from the organization of work and the discipline of procedures, and not
from the purchase of new resources, since the savings were obtained essentially through the review.
of flows and responsibilities.

A third type of intervention involved the automation of a screwing station for
a payment terminal manufacturer, with the goal of improving process quality,
To ensure standardization of the tightening sequence and reduce operational costs. The author led the...
implementation and participated in the acceptance of the equipment with the support of mode analysis and
Failure effects and experimental design, in addition to daily monitoring of
Production until the solution stabilizes. As the records for this project contain no results.
consolidated financial statements, it is not included in the cross-analysis, but is mentioned because it highlights...

Kaizen in electronic manufacturing combines organizational interventions with automation.
selective, always subject to prior analysis of the process. Table 1 summarizes the three cases.
selected for cross-analysis, based on the closing records of each project.

Table 1 - Summary of cases selected for cross-analysis

Case Process		Nature of the intervention	Tools and method	Results recorded
THE	Test of desktop computers	Review of the programming of functional tests, and automating manual steps. An operator now operates two pieces of equipment. the	Kaizen, production process analysis, selective automation	Productivity +58%. Estimated annual savings of US$1.24 million.
B	Test of notebooks	Eliminating waste and streamlining and operations, with a reduction in the number of operators.	Kaizen, loss analysis	Productivity +22%. Estimated annual savings of US$1.1 million.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

Case Process		Nature of the intervention	Tools and method	Results recorded
W	Lamination of photovoltaic modules	Handling detractors related to mill revenue parameters by a team of Production, Quality and Engineering	Kaizen cycle PDCA, defect data analysis	Return +1%. Recipe defects - 92%. Productivity +30%. Estimated annual savings of US$437,000.

Source: compiled by the author based on project closure records (2016-2021).

7 KAIZEN IN THE LAMINATION PROCESS OF PHOTOVOLTAIC MODULES

The manufacturing of photovoltaic modules involves the interconnection of cells, the assembly of The combination of the front glass and the rear protective layer, the lamination, the assembly of The frame and junction box are then fitted together, and final tests are performed. Lamination is the stage where the assembly is... subjected to heating and vacuum so that the encapsulating material surrounds the cells and ensures the mechanical and electrical integrity of the module throughout its service life. The parameters of The temperature, time, and pressure defined for each cycle of the equipment make up what... The industry calls the process recipe. In the unit studied, the modules were verified in Solar simulation testing equipment, known as Flash, that measures the curve characteristic of current and voltage, of electrical insulation, known as HIPOT, and of Electroluminescence, known by the acronym EL, allows the identification of microcracks and other Flaws not visible to the naked eye.

The author was responsible for the deployment, installation, and maintenance of this equipment. testing and, after international technical training on configuration, calibration and analysis of based on measurements, preventive maintenance plans were developed with defined frequencies and... Check items related to safety, engines, belts, and calibrations. This point This is relevant to understanding the C. Nakajima case (1988), in formulating the maintenance total productive capacity showed that losses due to defects and rework are among the major losses that They reduce the overall efficiency of the equipment, along with downtime and speed losses. An uncalibrated testing device not only fails to detect defects, but also This generates misleading data about process yield. The reliability of the measurement is therefore... A prerequisite for any data-driven improvement project.

Case C focused on reducing defects in the rolling process, specifically those assigned to the equipment's revenue parameters. The author acted as co-leader of a multidisciplinary team comprised of representatives from Production, Quality, and Engineering

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

of Equipment, and the project was conducted according to the PDCA cycle, with data analysis.
of defects, identification of the main detractors, implementation of countermeasures and the
verification of its effectiveness. The choice of a multidisciplinary approach was not accidental.
defects associated with the recipe lie at the intersection between the behavior of the materials,
observed by Quality, the equipment adjustments, dominated by Engineering, and the practices
of operation, known to Production, so that none of these areas, in isolation,
I had all the information necessary for a consistent diagnosis.
Closing records indicate a 1% increase in process yield, a reduction of
92% of defects associated with the lamination process, a 30% increase in productivity and
Estimated annual savings of approximately US$437,000. A 1% increase in income.
It may seem modest when viewed in isolation, but it takes on another dimension in a...
high-volume line, in which each yield point corresponds to a quantity
A significant number of modules are no longer rejected or reworked. The magnitude of the reduction
The number of defects, in turn, suggests that the causes acted in a concentrated manner, a pattern consistent with...
with the Pareto principle discussed by Juran and Godfrey (1999), and that the prioritization of
The main detractors were decisive in turning the team's effort into a result.
Measurable within a relatively short timeframe.
Case C also illustrates Spear and Bowen's (1999) observation that continuous improvement
It operates most effectively when process specifications are treated as hypotheses.
explicit and verifiable. The laminator recipe is exactly that type of specification, a
a set of parameters that expresses a hypothesis about the conditions that produce a
an integral module that can be tested and reviewed in light of defect data. Van Aken et al.
(2010), when proposing a model for the design and management of Kaizen event programs,
They highlight the selection of the problem, the composition of the team, and the follow-up afterward.
The event is seen as an element that influences the success of initiatives. In the case analyzed, the
a combination of a well-defined problem and a team with the necessary skills.
Complementary methods and an explicit verification method seem to have been what allowed
To transform the dispersed knowledge across different areas into a stable solution.

8. Cross-analysis of results and supporting factors

A comparison between the three cases reveals consistent patterns. In all of them, the gains
They mainly resulted from reviewing the content of the work, the logic of the test, or the...

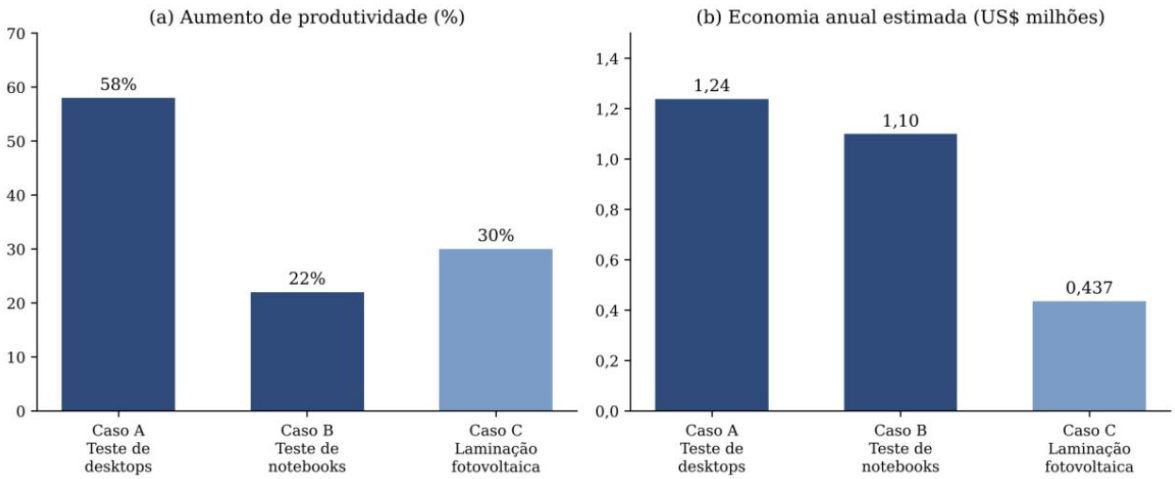
This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS – Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

Automation depends on process parameters, not on the acquisition of new production equipment. was present in Case A, but as a consequence of the process analysis and restricted to the stages. where manual intervention did not add value. Taken together, the three projects recorded estimated annual savings of approximately US$2.78 million, of which about 44.7% 39.6% correspond to Case A, 39.6% to Case B, and 15.7% to Case C. Figure 1 shows the... productivity increases and estimated annual savings for each case, allowing visualization. that the order of cases according to the percentage gain in productivity does not coincide with the order According to financial economics, this confirms that both indicators capture dimensions. different from the result.

Figure 1 - Increase in productivity and estimated annual savings in the three cases analyzed.



Source: compiled by the author based on project closure records (2016-2021).

The discrepancy between the two orderings deserves careful interpretation. Case C It showed a higher productivity gain than Case B, but lower financial savings. which can be explained by the difference in the nature of the losses treated. In the test cases of With computers, the economy was strongly associated with the reduction of the workforce allocated to them. seasons, a direct and recurring financial impact effect. In the case of lamination, the savings This resulted primarily in a reduction of defects and an increase in yield, the value of which depends on... Cost of rejected materials and processed volume. How productivity indicators contribute. They were calculated according to distinct internal definitions in each line, as explained in Methodologically, the comparison should remain within the realm of general trends, without the percentages should be treated as equivalent measures of performance across cases.

The issue of sustaining earnings is central to the literature. Bateman (2005) shows that the The results of process improvement programs often deteriorate after the...

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google
RCMOS - Multidisciplinary Scientific Journal The Knowledge.
ISSN: 2675-9128. São Paulo-SP.

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

formal closure of the initiatives, and identifies the existence of follow-up actions and the
Incorporating changes into the area's routines as conditions for achieving gains.
maintain or continue evolving. Glover et al. (2011), when studying Kaizen events in
several organizations have reached a similar conclusion regarding the results on the
people, whose continued presence depends on the institutionalization of changes in the environment of
work. In the cases analyzed, the support mechanisms included the development of
procedures, team training, formal control of test kits, and plans for
Preventive maintenance of measuring equipment, elements that correspond to best practices.
which these authors associate with the durability of the results.
The effects of improvements on people require equal attention. Farris et al. (2009) showed
that the results of Kaizen events on the attitudes and skills of the participants are
associated with factors such as clarity of goals, team autonomy, and management support.
Netland (2016), in a study on critical success factors in the implementation of lean production,
It points to leadership commitment and employee empowerment as among the most important elements.
relevant, and discusses the extent to which the contingencies of each plant alter this importance.
relative. Saurin and Ferreira (2008), in turn, proposed guidelines for evaluating the impacts.
lean production has an impact on working conditions, warning that productivity gains
The gains achieved by reducing the number of operators may be accompanied by an intensification of work.
The records of the cases studied did not include formal ergonomic assessments, which constitutes
a limitation to be considered in future studies.

Finally, the case studies allow for a discussion of the relationship between Kaizen and Industry 4.0. (Buer, Strandhagen)
Chan (2018), in mapping the literature on the subject, identified that lean manufacturing
and digital technologies tend to be treated as complementary, and they proposed an agenda
research to examine this relationship. Tortorella and Fettermann (2018) found, in
Brazilian companies: positive association between the adoption of lean practices and the implementation of
Industry 4.0 technologies. The reported experience is consistent with these findings. The record
Automatic rendering of results at local test stations and statistical analysis of performance of
stations represent early forms of systematic data capture and use, which only produced
Value because they were embedded in pre-established and standardized processes. A
Digitizing an unstable process tends only to make its instability more visible.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

CONCLUSION

This article analyzed three Kaizen projects conducted between 2016 and 2021 in a unit of Contract electronics manufacturing, two in computer testing lines and one in the process. of photovoltaic module lamination. The results recorded include increases of Productivity increases of 58%, 22%, and 30%, and a 92% reduction in defects associated with the recipe. lamination, a 1% increase in the yield of this process and an estimated annual savings of approximately US$2.78 million across all cases, which confirms the potential The economic benefits of continuous improvement in technologically intensive segments.

The main finding of the study is that the most significant gains did not depend on... acquisition of new production equipment, but from the review of the content of the work, of Test logic and process parameters. This finding aligns with the classic proposition. from Imai (1986) and with Shingo's (1989) critique of improving isolated operations, and reinforces that Analysis of the process must precede any investment decision, otherwise it risks becoming automated. losses instead of eliminating them. Automation, when it occurred, was selective and subordinated to this. analysis, and not the starting point for interventions.

The second finding refers to the importance of team composition and methodology. In three cases, the participation of professionals from different areas, and the disciplined use of the cycle PDCA allowed for the gathering of scattered knowledge and the objective testing of hypotheses. The Case C, in particular, shows that problems situated at the intersection between materials, equipment and Operational practices would hardly be resolved by a single area, however competent. that she was. The composition of the team, in this sense, should be defined by the nature of The problem lies with the current organizational structure, not the existing one.

The third finding concerns measurement. The reliability of the testing equipment, Assured by preventive maintenance plans and periodic calibrations, it proved to be a prerequisite for yield and defect data to guide decisions.

This aspect, often treated as a purely technical matter, turns out to be a component. from a management perspective, because the quality of improvement decisions is never superior to the quality of the measurements. that support them. Continuous improvement programs should therefore include the management of measurement systems are among their primary objects of attention.

Regarding the sustainability of the results, the cases indicate that formal procedures and training of the teams, control of test materials and preventive maintenance functioned as mechanisms for institutionalizing change, in line with what Bateman (2005) and Glover

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

et al. (2011) associate it with the durability of the gains. The study, however, does not have a series of data. historical records subsequent to the closure of the projects that allow confirmation of the permanence of long-term results. This gap reinforces the need for organizations maintain monitoring of indicators for periods longer than the formal cycle of each project.

Some limitations must be acknowledged. This is a retrospective study, conducted by The researcher participated in the interventions, which requires caution in interpreting the data. Despite the measures taken to reduce biases, the savings correspond to estimates. Internally, without audits, the productivity indicators followed different definitions in each line and there was no formal assessment of the effects on working conditions, which restricts the generalization of the results. The findings should therefore be understood as analytical generalizations, in the sense proposed by Yin (2018), and not as estimates Valid statistics for the sector.

From a management perspective, the results suggest that industrial organizations can achieve Significant gains can be achieved by investing in training your own teams in improvement methods. Continuous training, instead of resorting to ad hoc, external solutions for each problem. professionals capable of identifying losses, measuring them rigorously, and conducting experiments. Disciplined behavior constitutes an asset that accumulates over time and tends to be more valuable. more lasting than the gains from any single project. This perspective shifts the focus from Continuous improvement of the project for the training of people, which tends to broaden its reach and... longevity of its effects.

As suggestions for future research, longitudinal studies are recommended. monitor the evolution of the indicators after the projects are completed, the adoption of Standardized definitions of productivity that allow comparisons between lines and companies. the inclusion of ergonomic assessments and worker perception studies, and the investigation of Interaction between Kaizen and digital technologies in Brazilian plants in the following segments Electrical and electronic engineering and photovoltaics, a field still little explored by national literature.

REFERENCES

BATEMAN, Nicola. Sustainability: the elusive element of process improvement. **International Journal of Operations & Production Management,** Bingley, vol. 25, no. 3, p. 261-276, 2005.

BESSANT, John; CAFFYN, Sarah; GALLAGHER, Maeve. An evolutionary model of continuous improvement behavior. **Technovation,** Amsterdam, v. 21, no. 2, p. 67-77, 2001.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

BHUIYAN, Nadia; BAGHEL, Amit. An overview of continuous improvement: from the past to the present. **Management Decision,** Bingley, v. 43, n. 5, p. 761-771, 2005.
BUER, Sven-Vegard; STRANDHAGEN, Jan Ola; CHAN, Felix TS The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda. **International Journal of Production Research,** London, vol. 56, n. 8, p. 2924-2940, 2018.

COUGHLAN, Paul; COGHLAN, David. Action research for operations management. **International Journal of Operations & Production Management,** Bingley, vol. 22, no. 2, p. 220-240, 2002.

DEMING, W. Edwards. **Out of the crisis.** Cambridge: MIT Center for Advanced Engineering Study, 1986.

FARRIS, Jennifer A.; VAN AKEN, Eileen M.; DOOLEN, Toni L.; WORLEY, June. Critical success factors for human resource outcomes in Kaizen events: an empirical study. **International Journal of Production Economics,** Amsterdam, vol. 117, no. 1, p. 42-65, 2009.
GLOVER, Wiljeana J.; FARRIS, Jennifer A.; VAN AKEN, Eileen M.; DOOLEN, Toni L. Critical success factors for the sustainability of Kaizen event human resource outcomes: an empirical study. **International Journal of Production Economics,** Amsterdam, vol. 132, no. 2, p. 197-213, 2011.

GODINHO FILHO, Moacir; FERNANDES, Flavio Cesar Faria. Lean Manufacturing: A review that classifies and analyzes the works, pointing out perspectives for future research. **Management & Production,** São Carlos, v. 11, n. 1, p. 1-19, 2004.
GOLDRATT, Eliyahu M.; COX, Jeff. **The goal:** a process of ongoing improvement. Croton-on-Hudson: North River Press, 1984.
HOLWEG, Matthias. The genealogy of lean production. **Journal of Operations Management,** Amsterdam, v. 25, no. 2, p. 420-437, 2007.
HOPP, Wallace J.; SPEARMAN, Mark L. **Factory physics.** 3rd ed. New York: McGraw-Hill/Irwin, 2008.

IMAI, Masaaki. **Kaizen:** the key to Japan's competitive success. New York: Random House, 1986.

IMAI, Masaaki. **Gemba kaizen:** a commonsense, low-cost approach to management. New York: McGraw-Hill, 1997.

ISHIKAWA, Kaoru. **What is total quality control?** The Japanese way. Englewood Cliffs: Prentice-Hall, 1985.

JURAN, Joseph M.; GODFREY, A. Blanton (ed.). **Juran's quality handbook.** 5. ed. New York: McGraw-Hill, 1999.

KRAFCIK, John F. Triumph of the lean production system. **Sloan Management Review,** Cambridge, vol. 30, no. 1, p. 41-52, 1988.
LIKER, Jeffrey K. **The Toyota way:** 14 management principles from the world's greatest manufacturer. New York: McGraw-Hill, 2004.
LINDERMAN, Kevin; SCHROEDER, Roger G.; ZAHEER, Srilata; CHOO, Adrian S. Six Sigma: a goal-theoretic perspective. **Journal of Operations Management,** Amsterdam, v. 21, no. 2, p. 193-203, 2003.

LITTLE, John DC A proof for the queuing formula: L = ÿW. **Operations Research,** Baltimore, vol. 9, no. 3, p. 383-387, 1961.
MOEN, Ronald D.; NORMAN, Clifford L. Circling back: clearing up myths about the Deming cycle and seeing how it keeps evolving. **Quality Progress,** Milwaukee, vol. 43, n. 11, p. 22-28, 2010.

MONTGOMERY, Douglas C. **Design and analysis of experiments.** 8. ed. Hoboken: John Wiley & Sons, 2013.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Machine Translated by Google

Year VII, v.1 2026 | Submission: 09/02/2026 | Accepted: 15/02/2026 | Publication: 20/02/2026

NAKAJIMA, Seiichi. **Introduction to TPM:** total productive maintenance. Cambridge: Productivity Press, 1988.

NETLAND, Torbjørn H. Critical success factors for implementing lean production: the effect of contingencies. **International Journal of Production Research,** London, vol. 54, no. 8, p. 2433-2448, 2016.

OHNO, Taiichi. **Toyota production system:** beyond large-scale production. Cambridge: Productivity Press, 1988.

ROTHER, Mike; SHOOK, John. **Learning to see:** value stream mapping to add value and eliminate changes. Brookline: Lean Enterprise Institute, 1998.

SAURIN, Tarcisio Abreu; FERREIRA, Cléber Fabricio. Guidelines for evaluating the impacts of lean production on working conditions. **Produção,** São Paulo, v. 18, n. 3, p. 508-522, 2008.

SCHROEDER, Roger G.; LINDERMAN, Kevin; LIEDTKE, Charles; CHOO, Adrian S. Six Sigma: definition and underlying theory. **Journal of Operations Management,** Amsterdam, v. 26, no. 4, p. 536-554, 2008.

SHAH, Rachna; WARD, Peter T. Lean manufacturing: context, practice bundles, and performance. **Journal of Operations Management,** Amsterdam, v. 21, no. 2, p. 129-149, 2003.

SHINGO, Shigeo. **A study of the Toyota production system from an industrial engineering viewpoint.** Cambridge: Productivity Press, 1989.

SPEAR, Steven; BOWEN, H. Kent. Decoding the DNA of the Toyota production system. **Harvard Business Review,** Boston, vol. 77, no. 5, p. 96-106, 1999.

STAMATIS, DH **Failure mode and effect analysis:** FMEA from theory to execution. 2nd ed. Milwaukee: ASQ Quality Press, 2003.

TORTORELLA, Guilherme Luz; FETTERMANN, Diego. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. **International Journal of Production Research,** London, vol. 56, n. 8, p. 2975-2987, 2018.

VAN AKEN, Eileen M.; FARRIS, Jennifer A.; GLOVER, Wiljeana J.; LETENS, Geert. A framework for designing, managing, and improving Kaizen event programs. **International Journal of Productivity and Performance Management,** Bingley, vol. 59, n. 7, p. 641-667, 2010.

VOSS, Chris; TSIKRIKTSIS, Nikos; FROHLICH, Mark. Case research in operations management. **International Journal of Operations & Production Management,** Bingley, vol. 22, no. 2, p. 195-219, 2002.

WOMACK, James P.; JONES, Daniel T. **Lean thinking:** banish waste and create wealth in your corporation. New York: Simon & Schuster, 1996.

WOMACK, James P.; JONES, Daniel T.; ROOS, Daniel. **The machine that changed the world.** New York: Rawson Associates, 1990.

YIN, Robert K. **Case study research and applications:** design and methods. 6. ed. Thousand Oaks: SAGE, 2018.

This article is published in open access under the Creative Commons Attribution license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.