Lecture Notes on Multidisciplinary Industrial Engineering
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Anish Sachdeva · Pradeep Kumar ·
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Operations Management and Systems Engineering

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Lecture Notes on Multidisciplinary Industrial Engineering

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ISSN 2522-5022 ISSN 2522-5030 (electronic)
Lecture Notes on Multidisciplinary Industrial Engineering
ISBN 978-981-15-6016-3 ISBN 978-981-15-6017-0 (eBook)
https://doi.org/10.1007/978-981-15-6017-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Chapter 1
Process and Instrument for Visual Inspection of Mechanical Components for Imperfections Evaluation in Land Removal Equipment

Alex Tenicota, Stalin Nuela, Cristian Redroban, Ángel Larrea, and Luis Contreras

Abstract The lack of a process and an instrument to serve as a tool to control the technical condition and maintenance of land removal equipment in material handling is an acute social and industrial problem. Hence, the definition of these tools is an essential factor of safe operation in the mining, oil, and construction industry, as major sources for the development of a country. Therefore, the results of this investigation are presented based on the objectives pursued by the design, validation, and analysis of the reliability of a process and instrument for visual inspection of mechanical components for land removal equipment, which constitutes an adequate and efficient tool for inspectors, operators, and maintenance team in need to evaluate tolerable imperfections and defects. To validate the results obtained, the Delphi method was applied and the agreement between experts was assessed using Kendall's coefficient. Moreover, the factorial analysis for principal components was carried out to assess construct validity. Thus, it is concluded that the tool represents a source of technical information that supports the decision-making considering operation and maintenance parameters evidenced in the inspection critical routes.

Keywords Process and instrument for visual inspection · Land removing equipment · Mechanical components · Operation and maintenance · Imperfections evaluation

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A. Sachdeva et al. (eds.), *Operations Management and Systems Engineering*, Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-15-6017-0_1

1.1 Introduction

The handling of materials assisted by land removal equipment should include the following: Scrapers, loaders, trackers or wheel tractors, backhoes, bulldozers, agricultural, and industrial tractors, and similar equipment, designed for heavy-duty jobs [15]. The various industries of oil, energy, construction, and mining, require equipment and technology necessary to perform heavy work and land or materials removal. However, according to the analysis of specialized work in technological development [11, 13], shows the shortage of regulation and control of operation parameters for land removal equipment, even though the productive matrix has undergone changes that represent an increase in productivity, and thus the need to optimize the mining, oil and energy exports, as evidenced by Ecuador.

According to the contributions that describe the Ecuadorian productive context [5, 7, 16], they mention that the industrial activity that uses heavy-duty machinery and land removal equipment has been generally regulated in the operational, health and occupational safety files of the Ministry of Labour and Employment, Ministry of Public Work and Transport and the Ecuadorian Institute of Standardization (INEN), through ministerial agreements, regulations, and rules that are based on parameters or minimum requirements to be fulfilled. However, specialized studies in land removal machinery as known internationally according to [5, 6, 10] recognize that the guarantee of correct management and conservation of the machinery operation needs the control and monitoring of the operation parameters of each component or system that causes economic problems or accidents resulting from failures or breakdowns, which could be overcome through maintenance actions.

According to the information from the scientific contributions of maintenance management, the visual technical inspection is a preventive maintenance activity developed in the operation of critical equipment, [19, 20, 22]. Even more, the specialized contributions in standardization of engineering processes such as [8, 9], consider visual inspection as a method of non-destructive testing or technical tool for monitoring condition and control of discontinuities and imperfections in operating parameters. “Discontinuities and tolerable imperfections may be considered as important defects to determine the rejection or repair of an object” [12].

The public and private companies belonging to the industrial sector, comply with international standards set out mainly by the Society of Automotive Engineers SAE, American Society of Mechanical Engineers ASME, American Society of material testing ASTM, and international standards organization ISO, which regulate the context of the production system of transportation processes under quality guidelines. For the sustainable operation of the land removal equipment as part of a productive system, regardless of the industrial sector, there is a need to regulate the vehicular fleet due to frequent failures in systems and components, which according to [2, 3] are caused by an unregulated working environment resulting in over-exertion, poor installations, lack of lubrication and contamination of lubricating oil. Despite this fact, several contractors who offer the service of land transportation using land removal equipment, in the great majority of Ecuadorian productive systems, have not evidenced the fulfilment of visual technical inspections based on the study of the operation parameters considering conformity or inconformity criteria of the working conditions demanded by international institutions.

It is therefore appropriate to identify discontinuities or imperfections, considering the operation and maintenance conditions of the mechanical components through a well-grounded, valid, and reliable visual inspection process. This research leads to the definition of strategies that promote technological, academic, and decision-making development, supporting the production and quality service of the public and private industrial sector, to regulate the operation of land removal equipment. The implementation of the process and the proper use of the visual inspection instrument as a condition monitoring strategy would be the most viable alternative, the same that at least should respond to the following questions: what are the imperfections to consider as a defect or tolerable for inspection?, what are the critical routes that evidence greater inspection results in mechanical components of the land removal equipment? and in which components are evidenced major problems of dissatisfaction recorded in inspection processes of land removal equipment?, as long as it agrees with the established high level of confidence and public acceptance.

The aim of the research is to show the results of the definition, validation, and analysis of the reliability of the process and instrument for visual technical inspection of mechanical components for the removal equipment to evaluate imperfections. For meeting the target, it is necessary to carry out tests, to compile and analyze criteria of professionals that take part in the operation and maintenance of land removal equipment in diverse industrial sectors. It is necessary for the instrument to consider the operating parameters according to standardized and field-experienced criteria, so they possess characteristics of measurement and assessment in the development of visual inspections. Therefore, the incidence of the defects can be identified, thus trying to determine the improvement actions to avoid possible breakdowns or accidents, with the optimization of essential activities of corrective, preventive, and improving maintenance (scheduled or unscheduled) [4, 21].

1.2 Methods and Materials

It constitutes an application research, transversal and non-experimental, formed in three stages: (a) Design of the process and instrument, (b) evaluation of its reliability and validity of content and, (c) analysis of the construct validity. The stages were described after the conceptual revision of the constructs as follows:

(a) Design of the process and instrument

The bibliographic review and the analysis of the information were necessary to specify and summarize the characteristics that define the normal working conditions to be considered for the structure of the process and instrument design. The basis of the approach for the design of both the process and the instrument was dimensioned by the functional, environmental, and documented data from inspections, of which 32 subdimensions were reviewed, which lead to the formulation, presentation and writing of 40 initial items that constitute the instrument. The formulation of the instrument documentary for the visual technical inspection of land removal equipment was defined to collect data from sources evidenced in the field according to the detail of sensitive or critical mechanical components. For the study, the regions with the highest humidity conditions were considered, such as the Amazon and the coast of Ecuador that utilize land removal equipment the most. The cases of mining, polyducts, constructions that require the process of land removal were considered for the study.

The evidence to be collected in the inspection process consists of the description of the functionality levels for the land removal equipment obtained from the status review of the mechanical components found in the inspection routes. In the inspection, routes are grouped the mechanical components to be monitored, according to standardized catalogues, called Caterpillar checklist, due to the mentioned company is the main manufacturer of land removal equipment. The critical inspection routes selected for the present study were located from different visual points including the view from the round, top view on the equipment itself, in the engine compartment, and inside the operator's cabin.

For the detail of critical components, catalogues of the main manufacturers distributed in the medium were taken into account, in addition to technical documents of international regulation specialized in machinery inspection topics, like the standard of railway and mobile cranes; ASME B30.5: 2014, standard of articulated cranes; ASME B30.22: 2016, safety standard for low and high lift trucks; ASME B56.1: 2010, so for each system the work capacity, safety measures and the levels of defects or faults that may occur were described.

For the selection of the logic of inspections, the results developed in scrapers, loaders, tractors, and excavators used for the assembly of petroleum derivatives pipelines as in [14], were taken as reference. Figure 1.1 shows the process of inspection for land removal equipment and details each of the stages.

Step 1. In the general data collection, the person in charge of the inspection gathers the information of the extension of the route, concentration points, responsible for operation and maintenance of each machinery, place and time in which the work is carried out and highlights the use of reference standards to explain the objectives and scope.

Step 2. In the contractor data survey or so-called company providing machinery services for land removal, the person in charge of the inspection reviews evidence that certify the fulfilment of technical norms and regulations of transit according to demand the productive process and contractual responsibilities are established.

Step 3. In the collection of the technical data of the equipment, the person in charge of the inspection gathers information that contemplates technical characteristics of the vehicle (Fig. 1.2) such as model, year of manufacture, mileage, load capacity, tonnage, type of transmission, and traction mode.

Step 4. In the inspection of the systems, the operating and service conditions are registered and evaluated, in five inspection routes observed from lower view

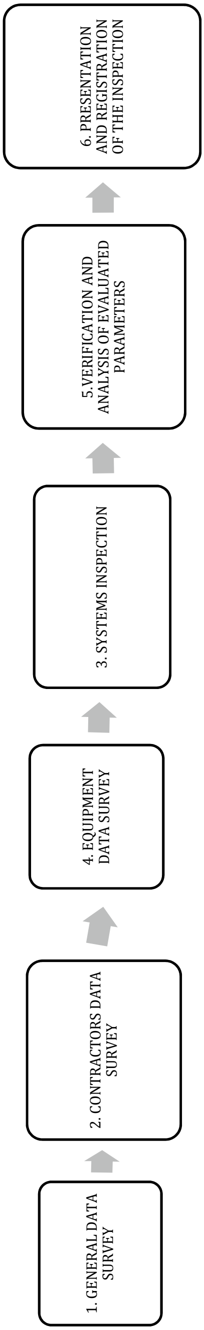

Fig. 1.1 Stages of the visual inspection process for land removal equipment

Fig. 1.2 Technical characteristics of the vehicle

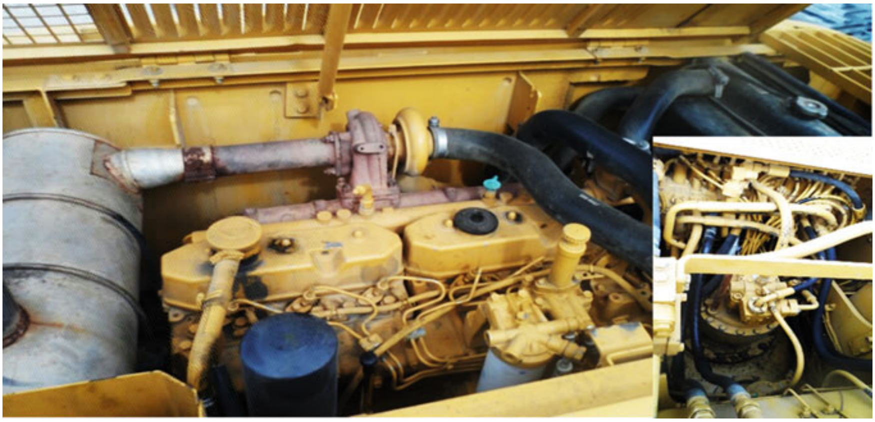

Fig. 1.3 Mechanical components to be inspected in the engine compartment route

without stepping onto the equipment, top view on the equipment itself, in the engine compartment (Fig. 1.3), and inside the operator's cabin (Fig. 1.4). The inspection reflects results according to the criteria of conformity and nonconformity, in the case of existing defects such as leak, crack, wear, cut, corrosion, or significant deformations that limit the operation of essential systems, such as hydraulic system, mechanical transmission system, electrical system, controls and signage, and lifting system. On the other hand, tolerable imperfections are considered as cases of dirt, missing minor mechanical elements, and low levels of fluids.

Step 5. In the verification and verification of evaluated parameters, the inspector and personnel responsible for the operation of the land removal equipment consolidate the results in the inspection and detail the assessments, in summary, showing the conformity or nonconformity according to technical discussions in agreement with regulations.

Fig. 1.4 Components to be inspected in the engine compartment route

Step 6. In the presentation and registration of the inspection, "the consolidated results are presented in reports to the industry supervision area in this case to certified companies that meet state requirements such as the case of the Ecuadorian Accreditation Service" [1].

(a) Reliability assessment and content validity of the instrument.

In order to understand the content validity, the Delphi method was applied with the purpose of defining the convergences, discrepancies, and consensus, on the viability of the documentary instrument and the proposed inspection procedure. Initially, a first-round survey consultation was conducted via email, to a significant sample of 35 professionals, selected with a margin of error of 5 and a 95% confidence level of a total of 38 technicians immersed in the inspection who work or who were part of certification companies in the country. The participation of the interviewees was used to define the level of knowledge about the operational context of the equipment for land removal within the mining, oil, and construction industry that requires the process of land removal. The determination of the coefficient of expertise k, categorized the people with more experience, relevance, and training.

To select the experts through the second round of questions, criteria of knowledge and argumentation (K_c, K_a) were considered, of which 60% were engineers who currently belong to the main certifying companies in the country, and the remaining 40% are engineers who previously participated in technical inspections of the operation for land removal equipment. The second round of questions to the selected experts was carried out in two stages so that in the first stage, the group of main parameters for the inspections were obtained and in the second stage, two additional parameters were incorporated according to the observation expressed by the participants. These questions referred to the selection and qualification of the level of incidence in the acceptance “conformity”, rejection “nonconformity” or observation of parameters to be measured by mechanical components of the land removal equipment, taking into account the incidence they have to cause defects or failures

To support the reliability of the instrument, the Cronbach’s Alpha was calculated, and to establish the agreement between the criteria of the experts, the analysis was carried out through the Kendall coefficient W when dealing with ordinal data. According to the work specialized in non-metric statistics [17] 1995, the Kendall coefficient is used when you want to know the degree of association between k sets of ranks, so it is especially useful when the experts are asked to assign ranges to the items, for example, from 1 to 4. The coefficient is 0 and the maximum 1, which is based on the sum of the ranges obtained from the different experts, it represents the minimum value assumed by the coefficient as 0 and the maximum as 1. “In the case that the coefficient is 1 shows perfect agreement among the evaluators, if it is 0 shows that the agreement is not greater than that expected at random, and if the value of the coefficient is negative the level of agreement is lower than expected at random” [18].

(b) Construct validation of the proposed instrument

The factorial analysis was performed by main mechanical components to evaluate the construct validity of the instrument and the logic of the inspection process. It was necessary to identify the existence of a correlation between the variables of the instrument by means of the Bartlett sphericity test, with which the factorial analysis was proven to be useful. As a reference, it was considered adequate for the values reached of $\alpha < 0.05$, and the Kaiser–Meyer–Olkin (KMO) sample adequacy measure, which indicated the intercorrelation of variables as a feasible value, for figures greater than 0.7. Next, the main results are presented:

Results of the reliability analysis and validation of the instrument’s content
The results of the first survey to the 38 professionals with experience in inspection show that 35 experts determine the totality of high and medium knowledge of the inspection process according to the critical routes proposed. The coefficient of competence of 82.3% (28 experts) is justified by experts with 5 or more years of experience in the inspection of land removal equipment according to similar work carried out and only 17.5% (7 experts) obtained an average level, justified between 1 and 5 years of experience and different arguments in the logic of the inspection process.

Regarding the second round, the knowledge coefficient (K_c) of 12 and 15 expert cases was around 0.9 and 0.8, respectively, as well as 2 and 6 cases between 0.6 and 0.7. With these results, it was decided to use the study for all the experts.

Of the 35 experts surveyed according to the individual criterion, a standardized Alpha coefficient of 0.7721 was obtained in accordance with the items mentioned in the instrument in which different levels of incidence are evidenced for the assessment of imperfections in mechanical components. Thus, reflecting acceptable reliability of the same. The symmetry of the items shown in Table 1.1 is adequate, as shown

Table 1.1 Results of the first phase reliability analysis of the designed instrument

Items (Critical routes of inspection)	Level of incidence for the assessment of imperfections detected in mechanical components of land removal equipment						Individual variance/total variance	Individual variance/total variance	Individual Alpha
	Very high	High	Medium	Low	No incidence	Surveyed			
From the ground	16	14	3	2	0	35	0.28644	0.71356	0.73455
On the machine	12	12	5	6	0	35	0.23709	0.76291	0.78535
In the engine compartment	11	19	3	2	0	35	0.26622	0.73378	0.75536
Inside the cabin	12	7	7	9	0	35	0.21025	0.78975	0.81298
Sum of variances				8.6255					
Criteria				Reliability coefficient (absence)				0 a 0.59	
				Reliability coefficient (acceptable)				0.59 a 0.99	
				Reliability coefficient (ideal)				1	
Reliability coefficient CRONBACH				0.7721					

Table 1.2 Results of the instrument application to the experts in the second round

Stages of the technology for management	Category 1 very high	Category 2 high	Category 3 medium	Category 4 low
From the ground	0.5294	0.9412	0.9706	1000
On the machine	0.7941	0.8529	0.9706	1000
In the engine compartment	0.5588	0.9412	1	0.3467
Inside the cabin	0.5294	0.8823	0.9118	1000

by the values of variance, so we can say that bias due to the lack of independence of the data is not supported empirically.

Knowing that the results of the first round of surveys to the experts is not enough, the second round shows proportional values of relative frequencies of each critical inspection route analyzed, which reflects the opinion of experts according to each determined category, see results in Table 1.2

The category of high level of incidence to assess the defects in mechanical components is composed of 4 items of the critical routes valued with scores greater than 0.50. The category of very high incidence level to assess the defects in mechanical components reflected higher cases for critical routes grouped on the machine, in the engine compartment, and inside the operator's cabin with higher frequencies over 0.8 which reflects the percentage ratio of the number of mechanical components of the mentioned route. In the category of high incidence all the stages were kept between the frequencies of 0.91 and 1.00, and for the medium incidence reached the frequency of 1.00 shown a greater number of mechanical components that are part of the inspection in these routes, however, the route in the engine compartment is the only one that showed a lower value in the fourth category, demonstrating that most mechanical components show an incidence in the assessment of the imperfection.

The results show that most of the experts categorize the inspection routes understudy, in very high and high incidence of cases that evidence nonconformity criteria or defects in mechanical components documented in inspections of the land removal equipment. This means the degree of adequacy of the mentioned instrument, therefore, the instrument is suitable to be applied. Once the construction of the instrument was finished, the concordance analysis by means of the Kendall Coefficient of Concordance was performed and its results show that the items of the instrument measured the same construct in consideration of the basic principles of Sufficiency, Clarity, Consistency, and Relevance. The results shown in graph 1 differentiate each category according to each concordance coefficient which coincided higher than 0.75 in all cases, so that statistically ($p < 0.05$) are significant. The results of the Kendall coefficient show that there was a high level of agreement among the experts as to what was measured in the instrument, therefore validating the instrument.

Table 1.3 Results of the factorial analysis of main components

Variables	KMO	*P* value	Factors**		
			1	2	3
– From the ground	0.835	0.000*	0.858		
– On the machine			0.825		
– In the engine compartment			0.769		
– Inside the operator's cabin				0.734	
– Less critical mechanical components from all inspection routes					0.672

Note * $p < 0.05$, ** C

Results of the construct validation of the proposed instrument (Factorial analysis by main components)
The application of the multivariate technique to evaluate the construct validity called the Bartlett test was statistically significant ($p = 0.000$), moreover, in the sample adequacy measure of KMO, 0.835 was obtained. The results of the multivariate technique are described in Table 1.3, where the correlated instrument variables plus a fifth variable that combines shared characteristics are identified. The technique of analyzing the main mechanical components that compose each inspection route was applied, were chosen some of the elements such: Axles—Final controls, differentials, brakes, hydraulic lines, hydraulic oil tank, bucket, rod bucket cylinder, retainers, windscreen wipers, windscreen washer, bar, frame, body, tires, pivot or swivel, hoses, and radiators (Figs. 1.5, 1.6, 1.7 and 1.8).

The main components were selected due to their higher volume of documented cases or evidence of imperfections evaluations such as defects around 81.8% of the total variance, and in the Varimax rotation, better representation and classification of coefficients are shown. The results of each represented and classified component show an easy interpretation, reduction of the items, and the group of three factors explained by this method, which give an approximate (81%) of the total variance.

- Factor 1: Intrinsic aspects to valuations of rejection or nonconformity imperfections. This factor relates the assessment results of crack (*see example in* Fig. 1.9), wear, corrosion or leaking defects, that show a high probability of occurrence in the mechanical components of the inspection routes from the ground of the equipment, on the machine, and inside the engine compartment of the earth removal equipment.
- Factor 2: Extrinsic aspects to valuations of rejection or nonconformity imperfections. This factor relates the assessment results of crack, wear, cut, or deformation defects that show a high probability of occurrence in the mechanical components of the inspection routes within the operator's cabin
- Factor 3: Aspects of valuation of tolerable imperfections. This factor is related to the results of the classification of cases of dirt, missing mechanical elements, low

Fig. 1.5 Hydraulic lines

Fig. 1.6 Bucket

Fig. 1.7 Tires or undercarriage

Fig. 1.8 Hydraulic oil tank

Fig. 1.9 Cracked tire

levels of fluids occurred, or the ones that manifest high probability of occurrence in the mechanical components of all routes

The results of the validation and reliability analysis show that the instrument allows to obtain objective, reliable and valid information on the evaluation of imperfections manifested as defects or tolerable within a process of visual inspection considering the parameters of operation and maintenance of components mechanics for land removal equipment describing their technical condition.

Regarding the results obtained during the inspection, they show conformity and nonconformity assessments according to the type of imperfection found, however; It should be understood that such assessments could be common in various types of road equipment, but in different operational contexts could vary depending on the workload, the city, the conditions of the roads and the type of maintenance that is carried out. The findings match with what was shown in the visual inspection work on the Cuenca—Pascuales pipeline [14], which constitutes in the technical condition determination of the road equipment from contractor companies.

The research contributes with the increase of the useful life of the mechanical components in each system by means of the identification of the imperfections evidenced by each of the experts interviewed, which confirmed cases of leakage, crack, wear, cutting, corrosion, and deformations, as determinants for the assessment of nonconformity or defect, and in the same way with tolerable imperfections. Moreover, the investigation showed the detail of the cases of nonconformity valuations of the main equipment for land removal, such as Excavators, Loaders, Bobcat, Bulldozer, which were displayed to each expert interviewed according to their experience in inspection and generated databases.

The main limitations of the study are summarized in the absence of the level analysis of agreement among the inspectors, therefore the results should be carefully reviewed before generalizing or extrapolating to another context not yet explored, and the sample size should have been increased for the multivariate analysis for future research.

Finally, it is recommended to carry out studies with more inspections that are part of diverse operation and maintenance conditions accordingly identified, and to gather several inspectors for each case, so that the observed variables could be affected in different ways.

1.3 Conclusions

The process and visual inspection instrument of mechanical components allow obtaining an objective, valid and reliable assessment of the imperfections which may be tolerable, and rejection of nonconformity.

The way in which the data was collected allowed us to study the level of incidence for the assessment of imperfections detected in mechanical components of land removal equipment. Thus, the instrument under the designed procedure provides a large amount of information that supports the decision-making, based on the operation and maintenance parameters that constitute the technical state of the equipment, which are shown in the critical inspection routes.

The result in the medium term is the identification of priorities for the development of maintenance activities of mechanical components classified by critical sectors that affect vehicle performance. The technical instruments that support the quality of the inspection processes contribute as a first-hand alternative to guarantee the functionality of the equipment and road safety.

References

1. Barahona, F., Arízaga, H.: Estudios de factibilidad para la creación de un nuevo servicio en el organismo de acreditación de empresas de inspección eléctrica de edificaciones. Universidad de las Fuerzas Armadas ESPE, Latacunga (2014)
2. Buchelli Carpio, L., Garcia Granizo, V.: Detección temprana de fallas en motores de combustión interna a Diesel mediante la técnica de análisis de aceite., s.l.: s.n (2015)
3. Caterpillar.: Excavadoras Hidráulicas., s.l.: CAT (2014)
4. Daneshjo, N., Kravec, M.: System States and Requirements of Reactive Maintenance. En Production Management and Engineering Sciences, Tatranská Štrba (2015)
5. Defaz Toapanta, V.E.T.d.M.: Desarrollo de un plan de seguridad de la información basado en las normas INEN ISO/IEC27000 para el Ministerio de Transporte y Obras Públicas. Pontificia Universidad Católica del Ecuador, Ambato (2015)
6. Galabru, P.: Tratado de procedimientos generales de construcción: Obras de fábrica y metálicas. s.l.:Reverté (1964)
7. Gómez García, A.R.B.S.P.: Incidencia de accidentes de trabajo declarados en Ecuador en el período 2011–2012. Ciencia trabajo **17**(52), pp. 49–53 (2015)
8. Jaffery, Z.A., Dubey, A.K.: Scope and prospects of non-invasive visual inspection systems for industrial applications. Indian J. Sci. Technol. **9**(4) (2016)

9. Li, Q., Ren, S.: A real-time visual inspection system for discrete surface defects of rail heads. IEEE Trans. Instrum. Meas. **61**(8), 2189–2199 (2012)
10. Lloret, P.B. 2. e. 2.: Maquinaria de obras públicas II: Máquinas y equipos. Volumen 2 (2003)
11. Molina, D.L.P., Vélez, P.E.R.: Cambio de la matriz productiva del Ecuador y su efecto en el comercio exterior **2**(2), 418–420 (2016)
12. Morillo, G.: Inspección visual. Niveles II y III. FC Editorial, Barcelona (2011)
13. Moscoso Jacome, R.E.: Programa de control del mantenimiento proactivo y correctivo en equipos mecánicos del transporte de hidrocarburos en el Ecuador, s.l.: s.n (2017)
14. Nuela S., Tenicota G.: *Inspección de parámetros de mantenimiento y operativos estandarizados de equipo de remoción de tierras en el poliducto Cuenca-Pascuales*. Riobamba, IDI—ESPOCH (2017)
15. Reese, C.D., Eidson, J.V.: Handbook of OSHA Construction Safety and Health. CRC Press, s.l (2006)
16. Sarango Ríos, E.E.E.P.T.d.M.: Plan de vigilancia de la salud para trabajadores expuestos a hidrocarburos aromáticos del Terminal Pascuales. Universidad de Guayaquil, Facultad de Ingeniería Industrial, Guayaquil (2016)
17. Siegel, S., Castellan, N.J.: Estadística no paramétrica, aplicada a las ciencias de la conducta, 4 edn. Editorial Trillas, Mexico DF (1995)
18. Sim, J., Wright, C.: The Kappa statistic in reliability studies use, interpretation, and sample size requirements. Phys. Ther. **85**, 257–268 (2005)
19. Tsang, A.H.: Condition-based maintenance: tools and decision making.. J. Qual. Maintenance Eng. **1**(3), 3–17 (1995)
20. Ventura, M.E.Z.: Gestión moderna del mantenimiento de equipos pesados. Ciencia y Desarrollo **18**(1), 27–37 (2016)
21. Vinnem, J.E., Haugen, S., Okoh, P.: Maintenance of petroleum process plant systems as a source of major accidents? J. Loss Prev. Process Ind. **40**, 348–356 (2016)
22. Viveros, P.: Propuesta de un modelo de gestión de mantenimiento y sus principales herramientas de apoyo. Ingeniare **21**(1), 125–138 (2013)

Chapter 2
Development of Computer-Aided System to Generate Tool Path for Single Point Incremental Forming Process Using MATLAB

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Abstract In the present paper, the work involved in generating tool paths for different part geometries using Single-point Incremental Forming (SPIF) process is discussed. The part geometries are cone, pyramid, cone with varying wall angle (with circular generatrix), pyramid with varying wall angle (with circular generatrix), hybrid shape (combination of cone and pyramid), hybrid shape with varying wall angle (with circular generatrix), parabolic and hemispherical. For this various SPIF process parameters were considered while developing MATLAB GUI based code. It takes SPIF parameters as inputs (geometric and forming parameters) for generating the required tool path. For the said geometries two tool path types are considered, i.e., incremental/profile and spiral/helical tool path. Tool path thus generated is first simulated using GWizardE (CNC program simulation software) and then validated using SPIF process setup. The said program can be used for tool path planning and generation for multistage Incremental Sheet Forming (ISF) process also. The present work is undertaken with the aim to reduce computational effort required for generating tool paths and to save time and cost for experimentation and research work in the domain of SPIF process.

Keywords Incremental sheet forming (ISF) · Wall angle · Step size · MATLAB · Graphical user interface (GUI) · Computer-aided design (CAD) · Computerized numerical control (CNC)

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A. Sachdeva et al. (eds.), *Operations Management and Systems Engineering*, Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-15-6017-0_2

Nomenclature

D	Top diameter of cone
d	Tool/punch dimeter
h	Forming height/depth
ISF	Incremental sheet forming
p	Step size or pitch
r	Tool/punch radius
SPIF	Single point incremental forming
∅	Wall angle or forming angle
CAM	Computer-aided manufacturing

2.1 Introduction

Single Point Incremental Forming (SPIF) is an advanced sheet metal forming process for the production of sheet metal prototypes and parts. It does not require a dedicated punch and dies system for forming of sheet as compared to other conventional sheet metal processes [1]. It can be easily carried out on three-axis CNC conventional milling machine. Desired target geometry is first modelled with the help of CAD software and then using Computer-Aided Manufacturing (CAM) software, tool path is generated in terms of G-code and M-code (i.e. CNC programming). A schematic layout of SPIF process is shown in Fig. 2.1. Researchers have applied SPIF process in many areas starting from medical and biomedical areas with the manufacturing of human prosthesis and skull cavity to some of the very complex industrial parts used in high-end aeronautical and automobile applications [2]. It is evolving an advanced sheet metal process that can be used for manufacturing of sheet metal prototypes with less setup and tooling cost [3, 4]. Tool path is generated using costly CAM software packages like Mastercam, Catia, etc. Cost of such software packages is significant. These CAM packages are not specially designed for the forming processes like SPIF process. The objective of present work is to develop a low cost and easy to use program which can generate tool path for selected part geometries.

Worldwide researchers have applied their efforts to develop a strategy to generate tool path in the domain of SPIF process. For example, Skjoedt et al. [5] applied efforts to develop a dedicated program that uses the coordinates of profile milling CNC code and converts them into a helical tool path with continuous feed in all the three axial directions. It is reported that the proposed helical program works satisfactorily only for pyramid and conical shape but for muffler, coordinates were divided into two sections in order to produce the required part. However, this work does not replace the requirement of CAM software package for generating the CNC codes. Malhotra et al. [6] proposed a strategy to generate spiral toolpath program for single point incremental forming. It is reported that better and accurate tool path was obtained in proposed methodology along with the reduced forming time as compared

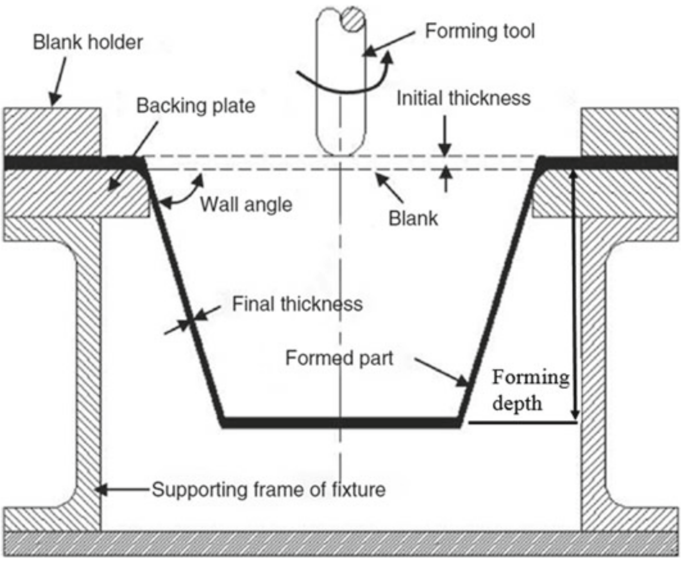

Fig. 2.1 Schematic representation of single point incremental forming [3]

with commercial CAM toolpath. This methodology can handle symmetric as well as asymmetric shapes and was a step toward automation of toolpath generation for incremental sheet forming process.

Lu et al. [7] developed feature specific tool path planning and generation algorithm for ISF process. It was pointed out that the tool path was generated according to specified critical edges with reduced forming time. Zhu et al. [8] proposed a spiral tool path generation method with constant scallop height based on the triangular mesh model. It was concluded that the proposed method was capable of generating a spiral tool path with constant scallop height according to the given tool radius. From the literature review, it is observed that very less efforts have been applied to develop a dedicated system for tool path planning and generation for SPIF process. The commercially available CAM packages are costly as well as it requires significant efforts and time in learning and operating them. Therefore, there is a need for developing such a system that can generate a tool path for various selected geometries. The proposed MATLAB based code can effectively generate tool path (both spiral, i.e., helical and profile) for several different experimental geometries (conical frustum, rectangular pyramid, hybrid, parabola, hemispherical, conical frustum with varying wall angle, pyramid with varying wall angle). Also, it takes SPIF process parameters (geometric parameters as well as forming parameters) as input for generating tool paths. The present work can also be used for multistage incremental sheet forming.

2.2 Steps Involved in Tool Path Generation

The complete tool path generation using the proposed system is done in three simple steps. It involves loading of program into editor window of MATLAB software. Thereafter run command is given. A graphical user interface pops up on the screen in which selection of tool path type (profile or spiral) and shape (cone, pyramid, etc.) can be done as per research work's requirement then click on proceed. After clicking on proceed another GUI pops on to the screen in which input of forming parameters like feed (in mm/min), spindle speed (in rpm) cutter diameter (in mm) and dimensions of selected shape along with the wall angle to be formed and step size needs to be given.

After supplying these necessary inputs which control the process click on generate. The required CNC program is generated in command window of MATLAB. From here the tool path can be copied and fed in the controller of CNC machine. The complete step by step procedure for tool path generation is shown in Fig. 2.2. The said procedure for tool path planning and generation is easy to use and does not require any special learning.

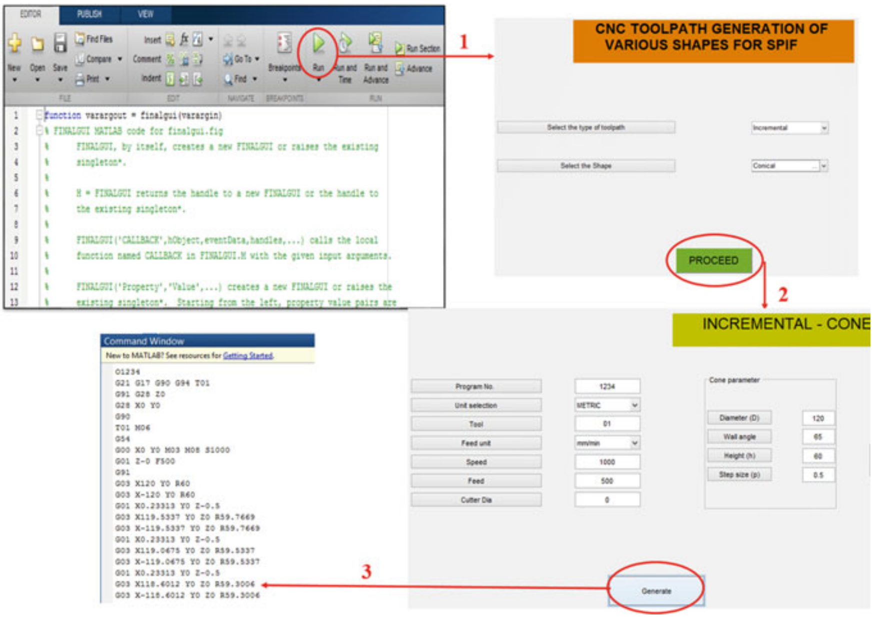

Fig. 2.2 Step by step procedure for tool path generation