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Evaluation Model of Mechatronizability

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Abstract: Competitiveness pushes companies to redefine their production units to offer multifunctional products. The integration of several functions requires the marriage of several disciplines of mechatronics that it is necessary to measure its dimension of integration. Because the problem of the designers or the professionals of the mechatronics is the one to know the level or the degree of the mechatronics which reflects equipment conceived or to be conceived for the market remains a necessity. This study seeks to understand the complexity of a mechatronic architecture to identify its constituents and define the parameters of a mechatronic system to estimate the mechatronizability of a product. After defining the utility and objectives of the metric, a methodology for the identification of the influential parameters and the formulation of the metric has been proposed. Drawing on the debatable achievements of the literature, four indicators were defined. In particular, the indicator of functional integration, dematerialization, complexity, and the general degree of mechatronics. These metrics of simple formulation were applied and validated on an electric pruning shear to estimate its mechatronic dimension. These metrics should allow manufacturers to simulate the mechatronic dimension of their production units and their competitive products.

Keywords: Metrics, Modeling, Product Design, Mechatronic, Mechatronizability

Introduction

The birth of mechatronics can be considered a revolution in the industrial world. As a result, the use of these systems has rapidly become widespread and currently influences almost all sectors of today's industry. The current economic environment is characterized by increasing customer demands for performance, quality, and price of products, which leads to a very dynamic product design environment with innovative product developments and life cycles. Product innovation then participates in obtaining and maintaining the competitive ability of the company competitiveness of companies (de Carvalho *et al*., 2021).

The term mechatronics responds to the need to define an industrial activity for the development of hybrid products that integrate, in an advanced and hitherto unseen way, technologies that have been used separately until now. It defines design engineering as aimed at the synergistic integration of mechanics, electronics, automation, and computer science in the design and manufacture of a product to increase and/or optimize its functionality (Tabourot and Balland, 2017). Mechatronics is also promoted as a technology that reduces costs and increases the added value of the product by increasing its functionality. This allows for a wider range of potential customers and thus access to different markets (Artema, 2016) (The same, 2017).

In light of the literature, two streams of thought are observed.

The mechatronics stream that aims to design and manufacture integrated products has continued to develop to the point that nowadays the scope of mechatronics covers many of our everyday or industrial objects and includes for example the development of the Internet of Things (Ajah *et al*., 2015) or even that of cyber-physical systems. The Internet of Things has been identified as a very high-growth sector very shortly. Indeed, these commonly used products offer a very wide spectrum of functional services. Mechatronics, on the other hand, is studied from several perspectives: Ontology development aspects for collaborative engineering are studied by (Damjanović *et al*., 2007) and also touch on transdisciplinary education (Pop and Măties, 2011), emphasizing the need for professional training throughout a mechatronics pathway and specific problem-solving methods as levers for success (Pop and Măties, 2010).

Connected objects, (Benghozi *et al*., 2012), (Ajah *et al*. 2015) or so-called cyber-physical systems that integrate into physical systems also present an important part of the research as well as the reliability of mechatronic systems (Demri 2009; Hammouda *et al*., 2013; Hamdani *et al*., 2022; Vitolo *et al*., 2022; Koltun and Pundel, 2022).

Mechatronics is therefore essential to the industry of the future and consequently to the factory of the future since without mechatronics there would be no intelligence or connectivity between machines. Furthermore, companies are providing as well as using mechatronic technology solutions. For example, a mechatronic design methodology adapted to the Delta Robot (Portillo-Vélez *et al*., 2022) and the use of axiomatic design and mechatronic multi-criteria profile in conceptual design (Ma *et al*., 2021). It is, therefore, appropriate to study how the companies that produce and market these products are organized. However, it is necessary to find a population of companies that allows concrete and precise targeting.

Yet another trend concerns metrics for modeling mechatronic design processes (Bonjour, 2008), (Bonjour *et al*., 2009), for facilitating the evaluation of architectures in systems engineering (Lo, 2013), for implementing agile processes in the preliminary design phases (Bricogne, 2015), or for instrumenting the profession of mechatronic system architect (Turki, 2008), (Bonjour, 2008), (Bonjour and Micaëlli, 2009), (Bonjour *et al*., 2013) and (Warniez, 2015). The mechatronic process is related to the life cycle of mechatronic products. It is a mechatronic process that allows achieving higher performance than traditional solutions, realizing new functionalities, and making mechatronic products more compact. This process requires the implementation of an interdisciplinary cooperative approach. Increasing and optimizing the functionality of mechatronic products requires the cooperation of several disciplines and the collaborative aspect is a necessary condition. Namely, it is necessary to make specialists from several different fields work together.

Considering the economic growth forecasts in the field of Mechatronics, many manufacturing Small and Medium Enterprises (SMEs) and Small and Medium Industries (SMIs) will have to develop industrial activities in the field of Mechatronics engineering in the very short term. These companies will have to be able to meet the needs for advanced components. They will therefore be led to adopt an organization and processes that will allow them to produce mechatronic products to be integrated into the economic dynamics caused by the development of these highly technologically integrated systems. If the large groups and most of the companies of intermediate size have already set up an organization and specific processes which allowed the realization of emblematic mechatronic products with great diffusion, this tendency is not generalized for the great majority of the SMEs. Moreover, the processes of large companies are not necessarily directly transposable to small companies due to many differences in organization and availability of resources, hence the need to master the mechatronics level of the product.

This study is conducted from the perspective of providing support tools to SMEs considering to evolve from a single-domain sectorial activity to a measurable multi-domain mechatronics activity. It is, therefore, useful to look for a model to evaluate the degree of mechatronics of a product to delimit the functional capability of the product to be able to design an adequate production unit.

Physical integration defines the integration of mechanical and electronic supports. In a broader sense, it indicates that the functions of a mechatronic product result from the combination of components of multi-domain technologies. Functional integration defines the addition of sensing, communication, information processing, and feedback functions to the basic mechanical functions. To qualify a mechatronic product, the standards necessarily lead us to take into account first the functions of the product. The method proposed here is therefore based on the functional definition of the product. The quantification of the physical or functional integration level requires them to identify and list the components and their technological domain used to satisfy the identified functions of the product. This means evaluating the functional flows for each component. Once these flows are established, it is then possible to evaluate different indicators quantifying the level of mechatronizability of the product.

This research aims to propose metrics for the evaluation of technological solutions adopted to meet the functional needs of mechatronic products. This evaluation should help companies to define the level of functional integration by identifying the particular characteristics of organizations that can design complex products and that belong a priori to a specific category: "Mechatronic" companies. Therefore, one of the major problems that this multidisciplinarity of mechatronic systems poses to experts is: "The evaluation of mechatronics at the design stage". To answer this problem, we have considered a method for the evaluation of the degree of mechatronics which is the use of metrics.

Concerning the evaluation of the degree of mechatronics, authors have already taken an interest in particular (Warniez, 2015; Granon, 2017; Tabourot and Balland, 2017; Fradi *et al*., 2021). But, their works have in common the fact that they evaluate in a compartmentalized way a mechatronic architecture. However, the structure of the product is hardly compartmentalized from the topological point of view (Samon and Tchouazong, 2022). It is also observed that some methods used arbitrarily determine the modules of the product. It seems appropriate to follow a reproducible approach for this purpose. The critical observation of these models will have to allow a critical synthesis to propose later an optimal metric of the mechatronizability of a product.

The objective set in this study is therefore to propose an approach that favors the quantitative evaluation of a mechatronic architecture to offer companies a tool that allows them to master the evaluation process of the degree of mechatronics of equipment from the design phase. To carry out this study, the structure of this article will start with the process of proposing the models (metrics), a method of determining the modules of the product, a method of calculating the indicators, and will end with an application of its models (indicators) on the electric pruning shears for validation.

Materials and Methods

Mechatronic Metrics Proposal Process

It is not easy to formulate a metric model that meets the expectations. Hence the need to have a reliable method to achieve the desired objective. Figure 1 presents the process of proposing the different models that we will formulate, starting with the analysis of the need for the metric, passing in turn through the definition of the objective of the metric, the identification of the influential parameters, the construction or design of the metric, the validation and finally a sensitivity analysis.

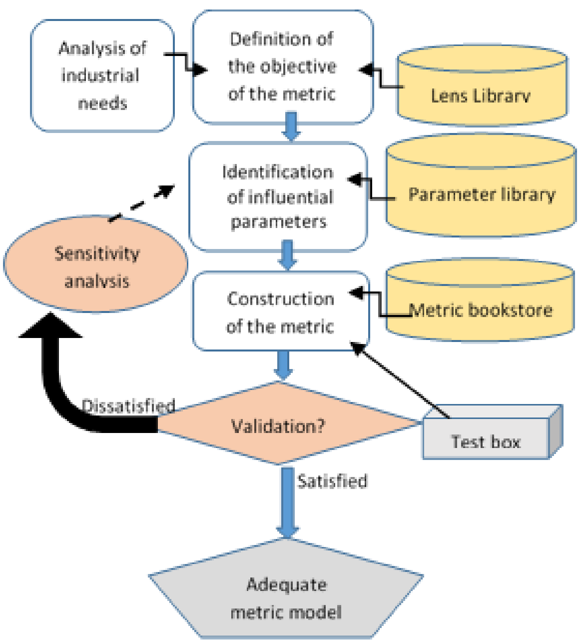

Fig. 1: Process for proposing a metric model

For the proposal of our metric model for the evaluation of the degree of mechatronics, we will therefore focus on the product metric category more precisely on the integration objective. Mechatronic systems are multidisciplinary systems that integrate subsystems or components from different disciplines interacting with each other, they have become more and more widespread due to their high level of functionality and integration (Bishop, 2007), as the more integrated a product is, the more functions it has. As a result, industrial products developed today are increasingly complex and must meet a growing number of integration requirements in particular.

Objectives to be Evaluated

The evaluation objective is based on three main factors: Functional integration, physical integration, and functional dematerialization.

A mechatronic system is characterized by its functional aspect. Functional integration consists in integrating as many functions as possible in the same product, in particular by combining several functions in a single component or by dematerializing some functions (Warniez, 2015). Here the goal addressed will be the collaboration of components in the realization of product functions. A physically integrated product is a product whose components are not always dissociable. The interpenetration of technologies is great and this leads to strong couplings (Tabourot and Balland, 2017).

In our case, functional dematerialization will come as close as possible here to the intelligence and autonomy of a product. By taking a closer look at the field of electronics, automation, and computer science because according to Tabourot these three fields give the product added value and thus promote its gain in performance.

Indeed, the more these domains are present in a mechatronic product, the more it becomes intelligent, autonomous, communicating, and thus performing.

Identification of Influential Parameters

This section discusses the influential parameters according to the different integrations mentioned above:

a. Functional integration

These are the functions fulfilled by the product and the components. The components are all the elements intervening in the realization of the functions of the product. These components will be classified into modules:

b. Physical integration

Still called functional complexity, the parameters influencing here are the domains and the couplings. The domains refer to the different disciplines encountered more and more in a mechatronic system or product. They

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are mechanics, electronics, automation, computer science, thermic, and optics. The first four are strongly present in the products and the others are starting to be more and more present. The couplings refer to the possible interactions between the six listed fields:

c. Functional dematerialization

In addition to the functions mentioned above, we must add the control functions as other influential parameters (these are the functions performed by a system involving the control part).

Formulation of the Models

Three formulations of models (metrics), also called indicators, have been proposed:

a. Functional integration indicator

This indicator measures the degree of integration and collaboration of the components in the realization of the functions of the equipment. Here we have grouped its components into modules. That is to say, the set of components fulfilling the same function. The model representing it is therefore given by the expression:

$$IntegMax = \frac{\frac{\sum_{fonctions} NMOF}{NTF}}{NM_i} \quad (1)$$

If IntegMax is null then each function is realized by only one module of the system and if IntegMax gives 1, then each Module of the system contributes to the realization of all the functions fulfilled (very strong integration):

NMOF: Number of modules per function
NTF: Total number of functions
NM: Number of modules

b. The physical integration indicator

It will reflect the level of interpenetration between the elements belonging to the different domains existing in each of the functions of the equipment. The expression used for the calculation giving the number of possible couplings between the domains is n(n-1)/2. We obtain a value of 15 corresponding to the number of possible couplings between these six (6) domains. The model of the functional complexity of a system is thus given by the following expression:

$$ComplexiMax = \frac{1}{15} \times \frac{\sum_i NC_o F_i}{NTF} \quad (2)$$

If ComplexiMax is null, the product is mono-domain. If ComplexiMax gives 1, the six domains are present in each of the product functions, with:

NCoFi: Number of couplings per function:

i: Functional dematerialization indicator

c. Functional dematerialization indicator

This indicator measures the degree of integration of electronic, computer, and automatic fields in the product. It reflects the level of communication, intelligence, and autonomy of the equipment. It is given by:

$$DemMax = \frac{NFIC}{NTF} \quad (3)$$

with,
NFIC: Number of functions involving the command

The closer it is to 0, the less intelligent the product is. The closer it is to 1, the more intelligent the product is:

d. The general level of mechatronics

It will be a question of defining the general Degree of Mechatronics (DGM). Indeed, whether it is for DemMax, ComplexiMax, or IntegMax, it is clear that each of these models evaluates a specific aspect of the degree of mechatronics of equipment. A perfect mechatronic system must be a functional (functional integration), structural (physical integration), and technological (intelligence) whole. The overall Mechatronic Degree of a product which will take into account all aspects of a Mechatronic architecture will be the sum of the three indicators formulated by:

$$DgM = \beta\left(DemMax + ComplexiMax + IntegMax\right) \quad (4)$$

The closer DgM is to 0, the less mechanical the product is. The closer DgM is to 1, the more strongly the 6 defined areas are present in the product and the value of 1 will in turn show a maximum degree of mechatronics. β Represents the weight of each indicator. The sum of these must be equal to 1, i.e., 1/3 per indicator.

Formation of the Modules

Evaluation of the Links between Component

To assess the connections between the components of the system, it is necessary to make a good choice of the disassembly parameters of the said system. The literature presents 14 parameters, which is far too many. On the other hand, (Djami *et al*., 2020) draw up a reduced list of parameters to best represent the facets of non-destructive disassembly of a product or system that can be used in its design phase. There are 6 parameters and for each of them, a scale of values or score is created and the different values

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make it possible to represent the main possibilities and to classify them into Types of Contacts (TC), Types of Combinations (TCO), Dismantling tools (OD), Number of Dismantling Directions (NDD), Operator Qualification (OQ), Equipment Required (ER). Table 1 is related to each of these parameters.

Use of the Clustering Algorithm

Clustering is a process that partitions a data set into meaningful subclasses (Djami *et al*., 2020). The clustering algorithm takes place in 3 steps. But in the context of our work, we will focus on the first step which deploys a clustering timeline of all components into modules. This step allows rearranging consecutively the rows and columns of the matrix modeling the relations between the components of a product or system, according to a similarity index until obtaining the diagonal blocks. Thus, all the components that are in maximum interaction are grouped to form modules. To find the number of modules in our system, the expression proposed by (Ericsson and Erixon, 1999) is used:

$$0.5\sqrt{NCP} << NM << \sqrt{NCP} \quad (5)$$

NCP: Number of product components

The grouping of components into modules is done in several steps and according to Fig. 2 below.

At the end of the obtained clustering, we will have an optimal clustering of modules if each module verifies the relation 2 (Ericsson and Erixon, 1999):

$$\frac{NCP}{NMPOYCM} << NCM << \frac{NCP}{NMICM} \quad (6)$$

NMOYCM: Average number of components in a module
NMICM: Minimum number of components in a module

The Evaluation Process of the Degree in Mechatronics

For the evaluation process (Fig. 3), the functional analysis of the product, in particular by looking at the octopus diagram and the FAST diagram, is made up. This is done to get a list of all the functions of the product. Once the list of all the selected functions is established, the different indicators defined are calculated to deduce the general degree of the mechatronics of the product.

Table 1: Identification of linkage parameters and their scores

Parameters	Descriptions	scores
Types of contact	No contact	1
	Punctual	2
	Linear	3
	Surface	4
	Multi point of contact	5
	Multi contact surface	6
Types de combinaisons	Put	1
	Insertion, screwing, riveting	2
	Turn	3
	Combine	4
	Gluing, welding	5
Number of disassembly directions	Over	1
	On the sides	2
	More than 15 cm deep	3
	Below	4
	Combined axes	5
	No visibility	6
Disassembly tools	No	1
	Compressed air tools	2
	Mechanical tools	3
	Provided by the manufacturer	4
	Specific	5
Qualification of the operators	No	1
	10 to 20 sec	2
	More than 30 sec	3
	Discussion	4
	Training	5
Equipment required	No	1
	Gloves	2
	Masks	3
	Fire protection	4
	Air filtration	5

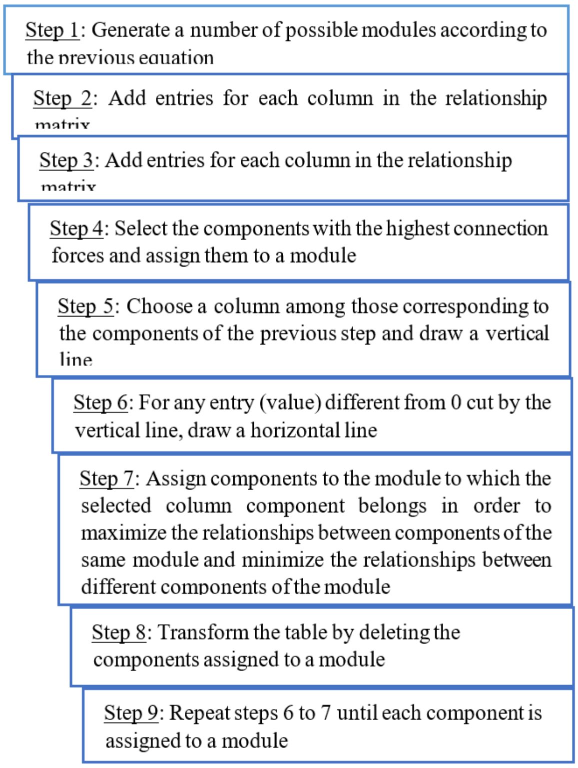

Fig. 2: Grouping steps of components into modules

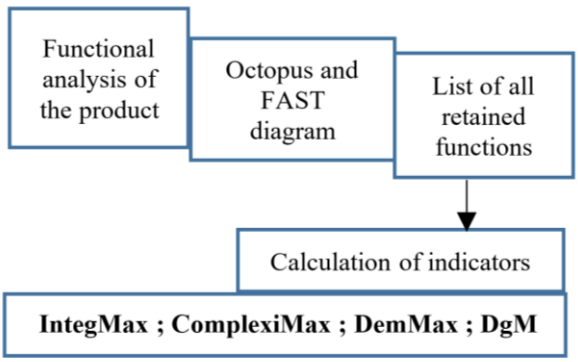

Fig. 3: Evaluation process of the degree of mechatronics

Application and Validation of the Proposed Model

One element often missing in the metrics proposed in the literature is their experimental validation. Fundamentally, the designer of the metric validates it in an industrial scenario to ensure that the value of the metric calculation is realistic. The main difficulty of the evaluation of real cases lies in the necessity to deal with the equipment data beforehand. The data from the electric pruning shears "Electrocoup plus" which is rather sophisticated equipment from the French company INFACO must be used.

The Electric Pruning Shears

Figure 4 presents the electric pruning shears "Electrocoup Brief equipment description: Electrical energy is supplied by a battery. This energy passes through an electronic card and is transmitted to a DC electric motor: With low inertia and an ironless rotor. The epicyclic gearbox transmits a rotational movement to a ball screw that transforms the rotational movement into a translational movement. This translational motion is then transmitted to the blade by two rods. The rotation of the motor depends on the action of the trigger (or the push button depending on the type of pruning shears) on a Hall effect sensor whose information is processed by the electronic board and is transmitted to the motor in the form of speed, the direction of rotation and intensity.

Figure 5 and 6 show respectively a general drawing and an exploded view of the electric pruning shears studied, accompanied by the component legend and characteristics in Tables 2 and 3.

Table 2: Components legend

No	Number	Name of the components
1	1	Electric motor
2	1	Epicyclic gearbox ratio 0.019
3	1	Conical torque 15*45
4	1	Cover 1G3
5	1	Body AG3
6	1	Hook
7	1	Blade
8	1	Cam
9	1	Torque adjustment spacer
10	1	Circlips
11	1	The front bearing 6000 E
12	1	Rear bearing AR6803
13	1	Blade shaft
14	1	Blade nut
15	1	Blade return spring
16	1	Locking screw for the nut
17	1	Rivet and blade roller
18	1	Mechanism cover
19	4	TF cover screw 3*8
20	2	Hook fixing screw TF 5*12
21	8	Cover and gearbox fixing screws
22	1	Connector mounting cap
23	1	Heat shrink tubing
24	2	Pinion stop screw CHC 4*4
25	1	On/Off contact

Table 3: Technical characteristics (DTsecateur, 1989)

Technical characteristics of the electric pruning shears	
Power supply	48 V
Pruning shears	940 g
Capacity	25 mm
Autonomy	8 h
No-load rate	150 strokes/min
Materials	Aluminum alloy and plastic housing

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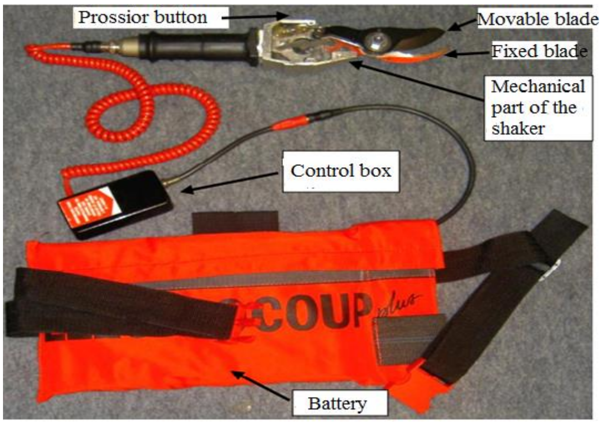

Fig. 4: Component of the Electrocoup plus pruning shears

Octopus and FAST Diagram of the Electric Pruner

Figures 7 and 8 and Table 4 show the octopus diagram, the Functional Analysis System Technic diagram, and the list of all the functions retained on electric pruning shears.

Functional Integration Indicator

This indicator is calculated by the expression given in Eq. 1. Before the calculation, the determination of the number of modules of the system is needed.

Formation of the Electric Pruning Shears Modules

For the formation of the modules, Table 5 depicts the evaluation links between components based on the previous Table 1 to 4.

This table of evaluation of the links of the electric pruning shears allows firstly to see the links between the components and secondly to give the total value of the links between each component. After defining the component links, the clustering algorithm is implemented (so the steps are given in Fig. 2).

Use of the Clustering Algorithm

By applying Eq. 5, the number of modules is:

$$NM = \sqrt{25} = 5$$

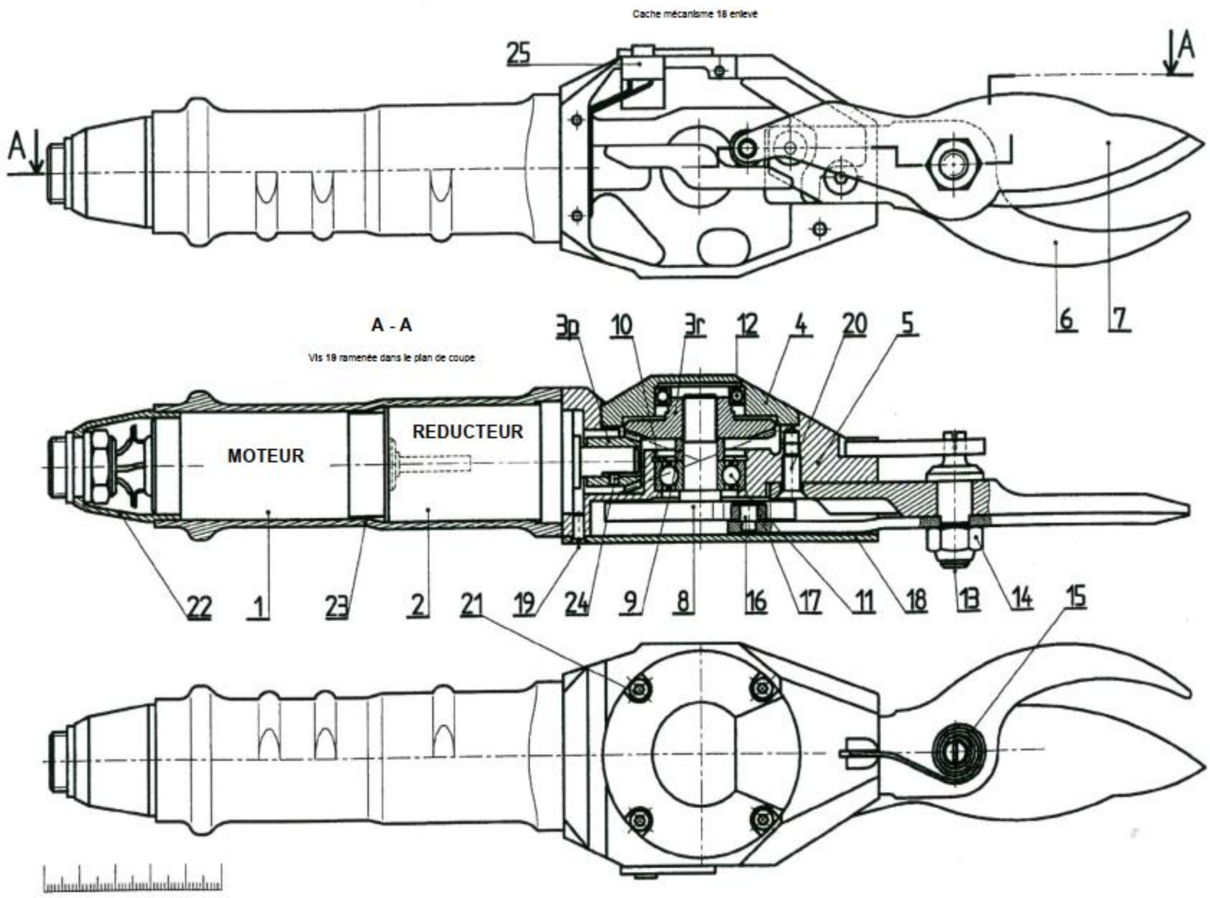

Fig. 5: Overall drawing of the electric shaker

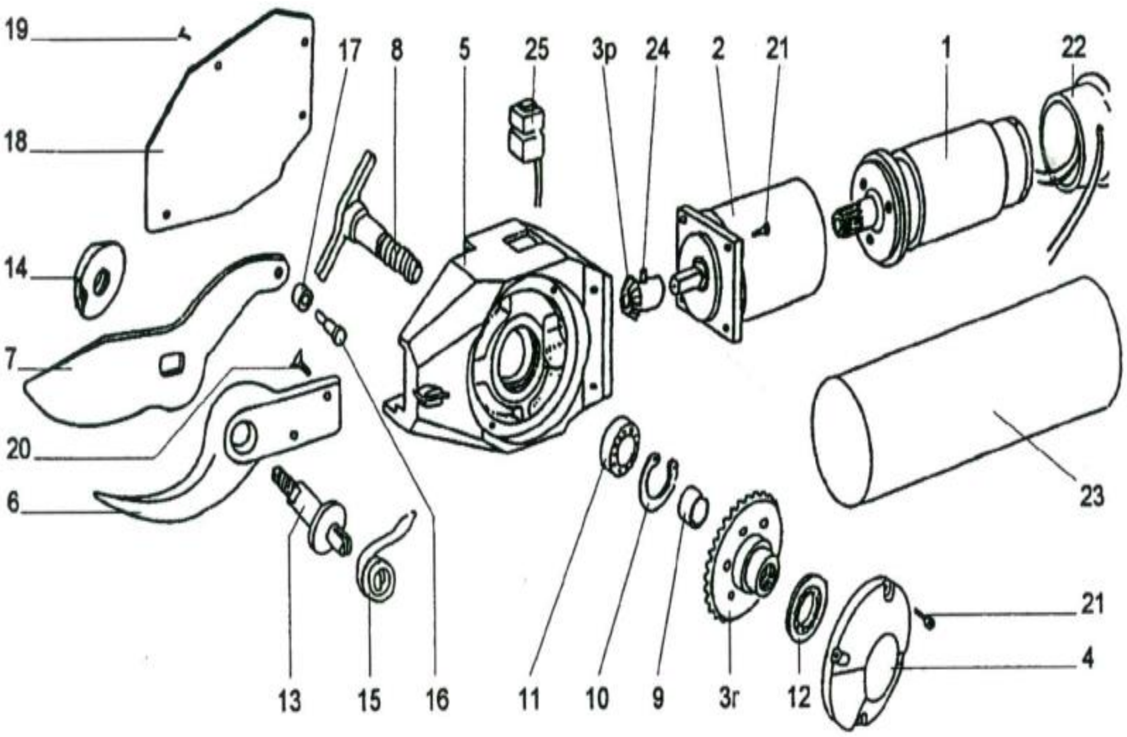

Fig. 6: Exploded view of Electrocoup plus electric pruning shears

But the complete range of electric pruning shears is also made up of a battery, cable (motor power cable + power cable of the box), and control box. Therefore, reattach them to a module. This will bring the total Number of Modules to NM = 6-adding entries for each column in the relationship matrix.

From the table of links (Table 5) and the whole list of components of the electric pruning shears previously listed, the cells of the matrix of relations of the components of the pruning shears are generated, and by applying, in turn, the sequence of steps given in Fig. 2, the relationship matrix is obtained as depicts in Table 6.

Then, the rest of the components are assigned to the modules, to maximize the interactions between the components of the same module and minimize the interactions between the components of different modules. Thus the constitution of each module is given in Table 7.

Functional Integration Indicator

Considering Eq. 6, it's found that the components of each module, therefore, verify this equation, so the grouping of modules is optimal. Once the modules have been found, the functional integration indicator is calculated as follows (Table 8).

The result is obtained by the calculation (Eq. 1): (57:14) /6 = 0.67. This shows that there is an important collaboration between the modules of the electric pruning shears and by ricochet between components.

Functional Complexity Indicator

It is given by Eq. 2 NCCF = number of couplings contributing to a function There is thus 1 function with 5 domains and thus 10 couplings, 5 functions with 3 domains and thus 3 couplings, 5 functions with 2 domains and thus 1 coupling, 2 functions with 4 domains and thus 6 couplings, 1 function with 1 domain and thus 0 couplings. The ComplexiMax functional complexity indicator is, therefore:

$$ComplexMax = \frac{1}{15} \times \frac{1+10+3+5+5+1+2+6}{14} = 0.2$$

This low value found allows us to note that all the domains as we have defined do not intervene sufficiently in the realization of the functions of the electric pruning shears, hence the low degree of mechatronics from the point of view of the functional complexity.

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Table 4: Different functions of the selected product

	Description	Criterion of appreciation
F 1	Cutting a branch with less effort	-Cutting capacity -Cutting force
F 2	To be pleasing to the eye of the user (aesthetics)	-Form -Color
F 3	Comply with worker safety standards	-Article R233-100 of the labor code
F 4	Ensure maximum autonomy	-autonomy duration: 8 h
F 5	Have a correct weight and size in hand	-Weight "in hands": 940 g -Length
F 6	Be fully portable	Total mass
F 7	Resist external conditions	
F 8	Shearing with electrical energy	
F 9	Vary the cutting speed	
F 10	Process the information	
F 11	Converting electrical energy into mechanical energy	
F 12	Adapting the mechanical energy	
F 13	Transforming rotational motion into translation	
F 14	Performing a shear	

Table 5: Evaluation links of pruning shear links

Links	TC	OD	NDD	QO	TCO	ER	Total
1-2	5	3	3	3	2	2	18
1-22	6	1	5	3	2	2	19
1-23	4	1	5	3	2	2	17
2-23	4	1	5	3	2	2	17
2-3	6	3	5	3	2	2	21
3-4	4	3	5	2	2	2	18
3-12	4	3	5	3	1	2	18
3-9	4	3	5	3	1	2	18
3-24	4	3	1	1	2	2	13
4-12	4	3	5	3	2	2	19
4-21	3	3	2	1	2	2	13
5-3	4	3	5	3	2	2	19
5-4	4	3	5	3	2	2	19
5-6	4	3	2	3	2	2	16
5-8	6	3	2	3	2	2	18
5-10	4	3	2	3	2	2	16
5-11	4	3	2	3	2	2	16
5-13	4	3	2	3	2	2	16
5-15	4	3	2	3	2	2	16
5-19	5	3	2	3	2	2	17
5-20	5	3	2	3	2	2	17
6-13	3	3	5	3	4	2	20
6-14	4	3	2	3	2	2	16
6-18	4	1	2	3	2	2	14
6-20	5	3	2	3	2	2	17
7-6	4	3	5	3	2	2	19
7-14	5	3	2	3	2	2	17
7-13	3	3	5	3	1	2	17
7-17	4	1	2	3	2	2	14
8-3	6	3	5	3	4	2	23
8-9	6	3	5	3	4	2	21
8-10	4	3	5	3	4	2	21
8-11	4	3	5	3	4	2	21
10-11	3	3	2	3	2	2	15
13-14	5	3	2	3	2	2	17
13-15	5	3	5	3	2	2	20
16-7	5	3	2	3	2	2	17
17-8	2	1	2	3	2	2	12
18-5	4	2	2	3	2	2	15
18-19	5	3	5	3	3	2	21
20-4	4	3	2	3	2	2	16
25-5	4	3	1	3	2	2	15

Table 6: Relationship matrix of the electric pruning shears with 14 functions and 6 modules

14F and 6M	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
Mechanics	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Electronics	1	0	1	1	1	1	0	1	1	1	1	0	0	1
Automatic	1	0	1	1	0	0	0	1	1	1	1	1	1	1
Computer Science	1	0	0	0	0	0	0	1	0	1	0	0	0	1
Optics	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thermal	1	0	0	0	0	0	1	0	0	0	0	0	0	0
NMCF	5	1	3	3	2	2	2	4	3	3	3	2	2	4
NCCF	10	0	3	3	1	1	1	6	3	3	3	1	1	6

Table 7: Constitution of each module

Components of Module 1	Components of Module 2	Components of Module 3	Components of Module 4	Module 5 components
3	5	6	8	13
2	4	7	10	12
1	14	16	11	21
23	15	17	12	22
24	9	19	20	25

Table 8: Functional integration indicator

14F and 6M	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	Total
M1	1	1	1	0	1	1	1	1	1	0	1	1	0	1	
M2	1	1	1	0	1	1	1	0	0	0	0	0	1	1	
M3	1	1	1	0	1	1	1	0	0	0	0	0	1	1	
M4	1	1	1	0	1	1	1	0	0	0	0	0	1	1	
M5	1	1	1	1	1	1	1	1	1	0	0	0	1	1	
M6	1	1	1	1	1	1	1	1	1	1	0	0	0	1	
NMCF	6	6	6	2	6	6	6	3	3	1	1	1	4	6	57

F = function; M = module; NMCF = number of modules contributing to a function

Table 9: Calculation of the dematerialization indicator

14 functions and 6 modules	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	Total
Command function	1	0	1	1	0	0	0	1	1	1	1	1	1	1	10

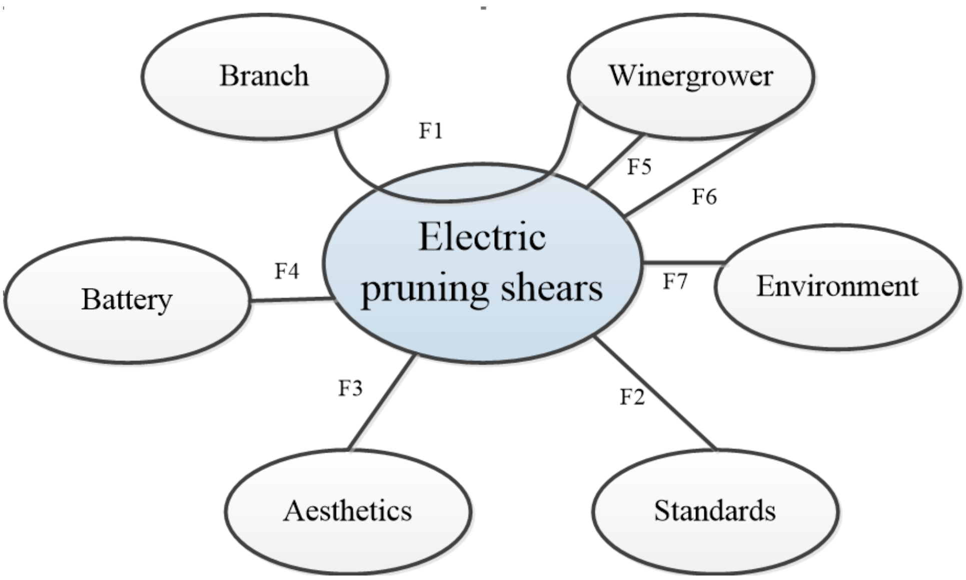

Fig. 7: Octopus diagram of the electric pruning shears in use

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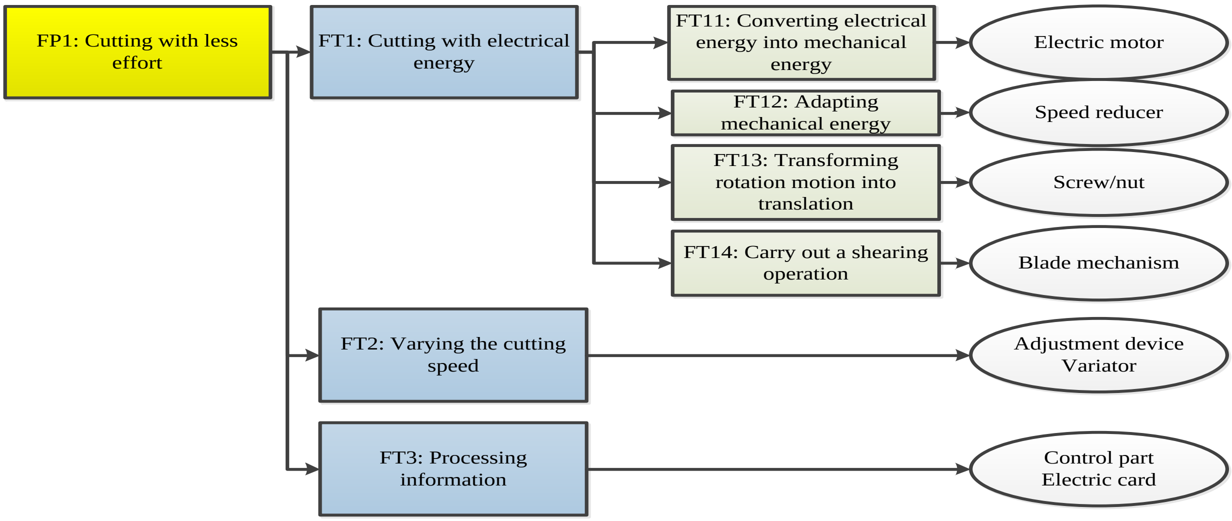

Fig. 8: FAST diagram of the electric pruning shears

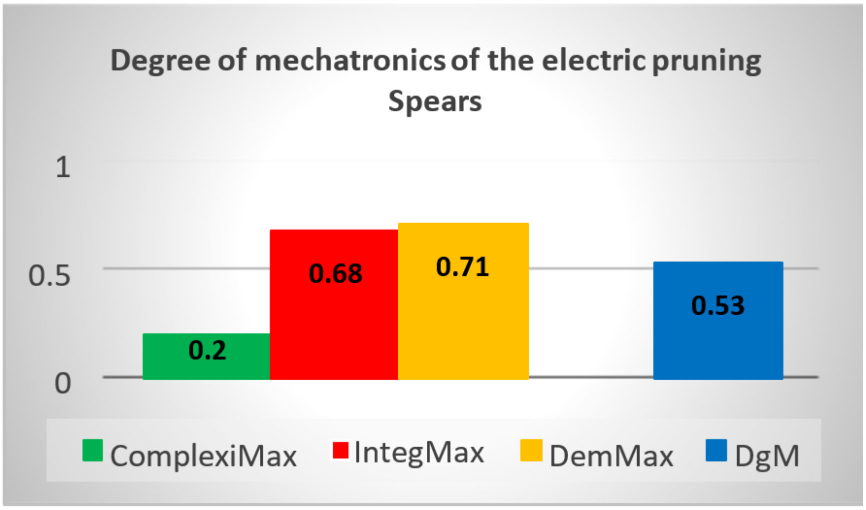

Fig. 9: Degree of mechatronics reflected in the electrocoup plus electric pruner

Dematerialization Indicator

It is calculated as illustrated in Table 9.

The result of 0.71 is obtained after the application of Eq. 3 and indicates that the fields of electronics, automation, and computer science are present in the product, which induces that the product or system is intelligent and also has a certain autonomy.

General Degree in Mechatronics

Here, the general degree of mechatronics of the product is calculated. So, the expression is given in Eq. 4 with the following result: 1/3. 0,71+1/3. 0,2+1/3. 0,68 = 0.53

This result of 0.53 rather above average represents the degree of mechatronics of the electric pruning shears studied and is very much in the image of our electric pruning shears as the product itself shows some aspects of intelligence, also presents very weak couplings in the realization of the product functions.

Summary of the Mechatronizability of the Electric Pruning Shears Electrocoup Plus

The summary of the four metrics computation is illustrated in Fig. 9. The "Electrocoup plus" electric pruning shears is a highly integrated, dematerialized product, but its complexity is well below average.

But in the end, we can see that the general degree of mechatronics reflected in the Electrocoup plus electric pruning shears is quite good because above average.

Table 10: Comparison of the main models in the literature

Authors	(Tabourot and Balland, 2017)	(Granon, 2017)	(Current authors)
Models	$IntegMax = \dfrac{\dfrac{\sum_{fonctions} NCF}{NF} - 1}{NC - 1}$	$IntegMax = \dfrac{\dfrac{\sum_{fonctions} NMF}{NF} - 1}{NM - 1}$	$IntegMax = \dfrac{\dfrac{\sum_{fonctions} NMOF}{NTF}}{NM}$
	$ComplexiMax = \dfrac{1}{28} \times \dfrac{\sum_{FC} NC_o F}{NF}$	$ComplexiMax = \dfrac{1}{28} \times \dfrac{\sum_{i} NC_o F}{NF}$	$ComplexiMax = \dfrac{1}{15} \times \dfrac{\sum_{i} NC_o F_i}{NTF}$
	$DemMax = \dfrac{NF\ EIA}{NFP}$	$DemMaxEIA = \dfrac{NF\ EIA}{NFP}$	$DemMaxEIA = \dfrac{NFIC}{NFF}$
		$DemMaxinfo = \dfrac{NF\ If}{NFEIA}$	DgM = (DemMax +
		$DemMaxdiag = \dfrac{NF\ d}{NFEIA}$	ComplexiMax + IntegMax)
		$DemMaxintev = \dfrac{NF\ It}{NFEIA}$	
		$DemMax = \sum_{i=1}^{i=4} \lambda_i\ DemMax_i$	
Description	NCF: Number of components per function	NMF: Number of modules per function	NMOF: Number of modules per function
	NF: Number of functions	NM: Number of modules	NTF: Total number of functions
	NC: Number of components	NcoFi: Number of couplings per function i	NCoFi: Number of couplings per function
	NcoF: Number of couplings per function	NFif: Number of information functions	NFIC: Number of functions involving the command
	NFEIA: Number of functions related to "E", "I", "An	NFd: Number of diagnostic functions	DgM: General degree in mechatronics
	NFP: number of functions of the product	NFit: Number of intervention functions	β: Equal to 1/3 for each indicator,
		λi: Types of DemMax	so 1 for the three indicators

Discussion

The process of estimating the mechatronizability of a piece of equipment has already been addressed by (Granon, 2017; Tabourot and Balland, 2017) with the motivation of knowing the mechatronic maturity of a company. They proposed 3 debatable metric models helping in this evaluation of the degree of mechatronics. The literature has put an emphasis more on the functional than a structural description of the mechatronic product. This makes the constitution of practicable metrics difficult. A limitation is also observed in the definition and constitution of the number of modules of the product while establishing the limit of the links.

Based on the previous works and to have a single real value representative enough of the structure of the mechatronic product, four metric models have been constituted. Apart from the highlighting of the clustering algorithm (to obtain the more reliable modules), the general degree of mechatronics that a system can reflect has been proposed. Table 10 is the one presenting our models compared to other models proposed in the literature.

Conclusion

Mechatronics is a new discipline that could allow unlimited functions of future products and very complex production units. It seems therefore necessary to be able to justify the multifunctional level of a product. A benchmark to evaluate and compare the degree of mechatronics of equipment of different generations or even of different manufacturers has been proposed. Four metrics have been postulated to evaluate the mechatronizability of a product, namely: The functional integration indicator, the functional complexity indicator, the functional dematerialization indicator, and the general mechatronics indicator. An application of these models has been validated on Electrocoup plus electric pruning shears. It is thus possible from now on to estimate the degree of mechatronics of a product at the design stage. This estimation approach is still perfect because a tangible product is more structural than functional.

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Author's Contributions

Jean Bosco Samon: Designed research plan, organized the study, contributed to the writing of the manuscript, and finally participated in all proofreading and reviewed the paper.

Brice Landry Tekam Guessom: Contributed to the writing of the manuscript and gathered essential data.

Ethics

I hereby the corresponding author of the manuscript declare that the manuscript titled: *Evaluation model for the degree of mechatronics*, has not been published, that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. It is not stolen or unsheathed from master's theses or doctoral dissertations that are not supervised by the author or of any other research. I take all the legal responsibilities in case this provided information is not correct. I make a sincere effort to ensure the accuracy of the material described herein. No fund has been received for this study. The use of part of the document or all of its content deserves to site the author or to seek his approval. I confirm that I have reviewed and complied with the relevant Instructions to Authors, Ethics in Publishing policy, Declarations of Interest disclosure, and information for authors. I am also aware of the publisher's policies concerning retractions and withdrawals.

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