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Lean product development – principles and practices

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Abstract: The purpose of this paper is to analyze articles about Lean Product Development. The works were classified according to principles and practices, the countries that have the applications, the sectors where it is being applied, the journals that publish articles about the issue and other relevant factors. In conclusion, the article presents a table of the authors and practices used. The methodology was a search on Emerald Insight and ISI Web of Knowledge, resulted in a universe of 289 articles published between 2007 and 2011. This paper synthesizes the trends in the literature and the results that are being obtained from the lean product development approach. The results showed that electronics, auto industry and capital goods sectors are those with the most lean product development practices presented in the articles. In terms of methodology, case studies predominate. The countries with the most applications are the United States and the United Kingdom. The lean approach is not always cited directly, in many situations the practices are applied in an isolated manner, given that in 77% of the work a direct connection was found with a lean method. In relation to the practices, the five most common were Simultaneous Engineering-Integration, Process Standardization, Early Supplier Involvement (ESI), Learning Network and Voice of Customer (VOC). Could be observed by the paper's originality that even with many studies in the field, there is still a gap to be explored, which is that there are no indicators to manage the new product development process. Thus, it explores the state of the art about Lean Product Development practices and principles, providing a definition of concepts and a framework for benchmarking to later evaluate how lean are Product Development Processes at the companies.

Keywords: product development, lean approach, practices, performance measures.

1. Introduction

Lean is an approach that seeks to eliminate "fat," or that is, all of the waste that causes harm to the system. The focus is on the client and the processes that add value in terms of price, deadline, quality and delivery including social and environmental criteria. The lean approach is not new. Although Japanese companies have used it since 1950, it can be seen that it came to be quite successful when it began to be treated systematically, integrating people, processes, technologies and tools.

Ward (2007) emphasized that the development and introduction of new products is essential to guarantee the sustainability of a business. Lean manufacturing and its tools are widely applied in manufacturing. Nevertheless, it does not help to have world-class lean production if the product manufactured is not what the client wants. The product development process, in addition to being able to capture the scope of what is of value to the client, is aimed at the operational and technological implications that will be found in a following moment in the manufacturing processes inside and outside of the company (DAL FORNO; FORCELLINI; PEREIRA, 2009).

Regardless of the sector in which the company operates or the type of product that it develops, some problems are common in the practice and in the literature. Waal and Counet (2009) enumerate them – managers give low priority to the implementation of performance evaluation systems, the implementation requires more time than expected, there are insufficient resources and capacity for implementation, the organization is an instable environment, there is a lack of commitment from management, there is lack of staff motivation, insufficient commitment from middle management, a lack of support from Information Technology, the organization does not have a clear understanding of its strategy, there is no learning network or departmental vision, there is difficulty in defining Critical Success Factors, a lack of focus on internal management and control, a difficulty in transforming the corporate strategy into individual objectives, difficulty in correctly defining the indicators, too much focus on results and not during the implementation process, a lack of daily accompaniment from management, a lack of leadership during coordination and implementation, difficulty in maintaining the implementation, difficulty in obtaining data for the indicators or the organization does not see the benefits of the implementation.

The lean approach can thus be understood as a way of doing more with less, given that the practices are counter measures for handling waste. This paper presents the state of the art of Lean Product Development. It presents a bibliographic study of periodicals from 2007 until September 2011, a classification of the most used practices, and of the indicators and improvements obtained with the application of lean product development at companies, the sectors that are most advanced, the countries with applications and other analyses and classifications. It also presents a bibliometric analysis of the literature about the concepts of *Lean*, *Product Development*, *Benchmarking* and synonyms, such as *Lean Design*, *Performance Measures* and their combinations. The publications were classified using various criteria.

To conduct the study of existing research, the databases *ISI Web of Knowledge*, CAPES portal of periodicals and *Emerald Insight* were used. Of the total universe, 289 articles were selected. After a reading of these articles, those which were not related to the themes were eliminated, leaving a sample to be analyzed of 247 studies.

This paper is organized as follows. The first section places in context the development of the products and the lean approach, it introduces the objectives and the methodology. Next, we present a bibliometric analysis of the studies according to the methodology used, journals that explore the issue, countries with studies and other relevant criteria. In section 3, the focus is on the practices and principles of product development, characterizing those most found and reported on by the authors.

2. Bibliometric analysis

An analysis of the periodicals that present the issues being studied found 75 different journals with articles about the issues, with 12 of these journals accounting for 55% of the articles selected as shown in Table 1 (DAL FORNO, 2012):

Table 1. Periodicals with the most articles about Lean Product Development (DAL FORNO, 2012).

Journal	*Quantity*
International Journal of Operations & Production Management	27
Supply Chain Management: an International Journal	20
Journal of Manufacturing Technology Management	15
Benchmarking: an International Journal	12
Industrial Management & Data Systems	11
International Journal of Productivity and Performance Management	9
Business Process Management Journal	9
The TQM Journal	8
Journal of Product Innovation Management	7
International Journal of Lean Six Sigma	6
International Journal of Physical Distribution & Logistics Management	6
European Journal of Innovation Management	6

Concerning the research methodology, most of the articles (41%) used a single or multiple case study, followed by surveys (31%), as seen in Figure 1.

The use of the term "lean" was also verified, because there are many practices in various fields of application (manufacturing, engineering, services, logistics) although a lean approach is not always implemented in its totality in a systematic form. Thus, 77% of the studies were found to focus on a lean approach.

Another analysis concerned the sectors that most apply the lean approach for product development. Many studies have more than one application, usually because they involve multiple case studies or surveys. Some studies could not be classified because they used generic terms, such as "misc." or "various" separating companies by type (service, manufacturing), by size (small, medium, large), by position (manager, operational) or type of project (innovator, incremental).

Figure 2 reveals that the sectors of Electronics, Auto-industry, and Capital Goods are those that most apply lean practices for product development. The electronics

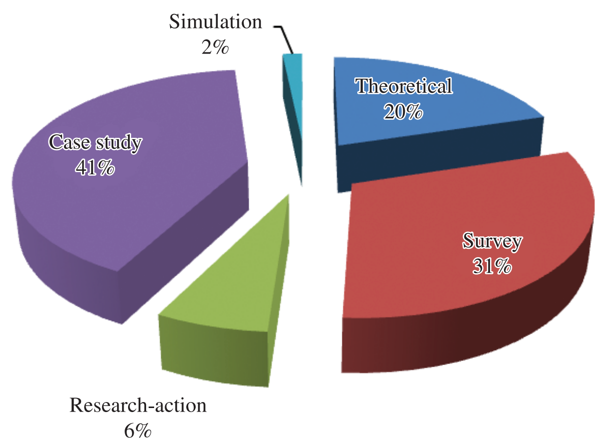

Figure 1. Methodology used in the studies analyzed (DAL FORNO, 2012).

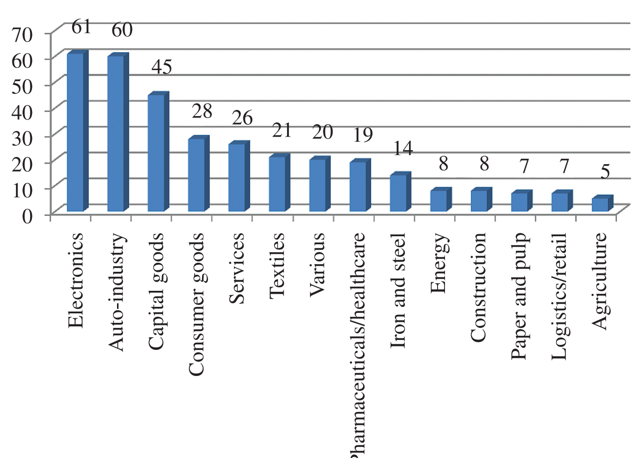

Figure 2. Number of studies by sector (DAL FORNO, 2012).

Table 2. Conceptual map of the themes approached and their relation with the main work (DAL FORNO, 2012).

Item	Description	Authors
Principles, Synonyms, Value	Conducts the activities that are important from the clients' perspective, assuring that the knowledge is achieved on time, at the least cost, with minimal changes and with a continuous flow of information by the entire organization.	Morgan and Liker (2008), Sobek (1997), Pessôa (2006), McManus, Haggerty and Murman (2005), Ballé and Ballé (2005), Kennedy, Harmon and Minnock (2008), Kato (2005), Seth, Seth and Goel (2008), Collin, Eloranta and Holmström (2009), Hilletofth (2009), Jorgensen and Emmitt (2007), Parry, Mils and Turner (2010), Fung, Chen and Yip (2008), Taylor (2006), Pawar, Beltagui and Riedel (2009), Allee (2009), Enquist, Edvardsson and Sebhatu (2007) and Hilletofth and Eriksson (2011).
Waste	Elements of a process that do not add value to the product such as overproduction, waiting, transportation, unnecessary processes, defects, reinvention, movement, stock, lack of discipline, and lack of integration of information technology.	Bauch (2004), Ward (2007), Morgan and Liker (2008), Saad and Gindy (2007), Haponava and Al-Jibouri (2009), Tam, Tam and Ng (2007), Cooper (2007), Ranky (2007), Yang and Su (2007), Seth, Seth and Goel (2007), Singh and Garg and Sharma (2010).
Value Stream Mapping (VSM)	Aims to develop a portrait of the current status to visualize some wastes and calculate the lead time. The improvements are planned later, in the future map and in the action plan.	Rother and Shook (2003), Locher (2008), Morgan and Liker (2008), McManus, Haggerty and Murman (2005), Dal Forno, Forcellini and Pereira (2009), Gurumurthy and Kodali (2009), Christopher et al. (2009), Hellström and Eriksson (2008), Childerhouse et al. (2010), Setijono and Dahlgaard (2007), Grant and Banomyong (2010), Singh, Garg and Sharma (2010), Thomas and Barton (2007), Parry, Mils and Turner (2010), Mottonen et al. (2009a), Menachof, Bourlakis and Makios (2009), Trkman et al. (2007), Oh and Kim (2007), Jacobs, Vickery and Droge (2007), Cheng, Chen and Mao (2010), Wang, Lin and Huang (2010), Haponava and Al-Jibouri (2010), Oppenheim, Murman and Secor (2011), Bhasin (2011) and Chiang (2009).
Voice of the Customer	Practice for identifying clients' needs (QFD, *Focus Group*, market research).	CAR (CENTER..., 2007), Akao and Mazur (2003), Gonzalez et al., (2008), McCoy, Thabet and Badinelli (2009), Carnevalli, Sassi and Miguel (2004), Manion and Cherion (2009), Garrido and Pasquire (2011), Afonso et al. (2008), Oppenheim, Murman and Secor (2011), Gautam and Singh (2008), Ledwith, O'Dwyer and Perks (2008), Cooper and Edgett (2008), Wellings, Willians and Tennant (2010), Cooper and Kleinschmidt (2007) and Prajogo and Hong (2008).
Chief Engineer	This the heavyweight project manager, who is responsible for all phases of the product project. This practice is related to the type of organizational arrangement, which is generally strong matrix.	Clark and Wheelwright (1994), Morgan and Liker (2008), Rozenfeld et al. (2006), Arnheiter and Greenland (2008), Holtzman (2011), Sawhney et al. (2010), Owens (2007), Christopher et al. (2009) and Summers and Scherpereel (2008).
Organizational Structure	For each type of project (incremental, innovative, platform, radical or follow source), there is a structure that is most suitable. For the lean approach, it is suggested that for radical and innovative projects the structure be of the strong matrix type. Meanwhile, for incremental projects, a structure by departments or function can resolve the issue.	Arnheiter and Greenland (2008), Mottonen et al. (2009a), Roh, Hong and Park (2008), Morgan (2007), Karlsson and Sköld (2007), Huang and Wu (2010), Visser et al.(2010), Knudsen and Mortensen (2011), Bergfors and Larsson (2007), Bassani et al. (2007), Kollberg, Dahlgaard and Brehmer (2007) and Oorschot et al. (2010).
Visual Management	Measures for detecting errors at the source so they do not go farther. Examples are parametric systems in CAD, *check lists*, detailed and standardized test plans. A visual framework with the schedule of the dates and phases of the projects underway assists visualizing compliance with deadlines and taking preventive measures on time, according to the frequency that project performance is checked.	Locher (2008), Parry and Turner (2006), Childerhouse et al., (2010), Quesada-Pineda and Gazo (2007), Singh, Garg and Sharma (2009), Arnheiter and Greenland (2008), Ranky (2007), Kumar and Antony (2008), Summers and Scherpereel (2008) and Mottonen et al. (2009a).
Project Library	This practice resumes the learning and the habit of registering the lessons learned to facilitate the reuse of knowledge.	Nonaka and Takeuchi (2008), Senge (2004), Morgan and Liker (2008), Waal and Counet (2009), Prajogo and Hong (2008), Ajmal, Nordström and Helo (2009), Meybodi (2009), Bilalis et al. (2007), Kira and Frieling (2010), Clark (2007) and Jeong and Hong (2007).

Table 2. Continuation....

Item	Description	Authors
A3 Reports	Practice used for problem solving, presentation of proposals and for strategic planning. Expresses the power of simplifying and encouraging the reflection.	May (2007), Dennis (2008), Sobek and Smaley (2010), Morgan and Liker (2008), Shook (2009), Chakravorty (2009), Olivella, Cuatrecasas and Gavilan (2008), Kumar and Antony (2008), Jeong and Hong (2007), Johnson, Sun and Johnson (2007), Smadi (2009), Singh, Garg and Sharma (2009), Lee and Peccei (2008), Waal and Counet (2009), Arnheiter and Greenland (2008), Laeequddin et al. (2010) and Fung, Chen and Yip (2008).
Modularity	Items of any nature in groups, which have standardized interfaces to be used in more than one product. In the automotive industry, the term platform is used to represent the modular development of families, which share similar global functions.	Rozenfeld et al. (2006), Walton (1999), Ulrich and Tung (1991), Ro, Liker and Fixson (2007), Pekkarinen and Ulkuniemi (2008), Jacobs, Vickery and Droge (2007), Ahmad, Schroeder and Mallick (2010), Pero et al. (2010), Rytter, Boer and Koch (2007), Wu and Park (2009), Hilletofth (2009), Pekkarinen and Ulkuniemi (2008), Howard and Squire (2007), Mahmoud-Joini and Lenfle (2010), Donk and Vaart (2007), Jacobs, Vickery and Droge (2007), Ahmad, Schroeder and Mallick (2010), Pasche, Persson and Löfsten (2011), Ranky (2007) and Bargelis, Kuosmanen and Stasiskis (2009).
DFx (DFMA, DFM)	This is a philosophy that seeks to facilitate assembly and disassembly beginning with the product design to minimize costs. Other considerations are also made, such as designing for the environment, services and Six Sigma. The benefits are reductions in the time-to-market, defects and assembly operations and calls for services.	Bargelis, Kuosmanen and Stasiskis (2009), Kincade, Regan and Gibson (2007), Caputo and Pelagagge (2008), Singh, Garg and Sharma (2009), Boyle and Scherrer-Rahtje (2009), Mottonen et al. (2009b), Jacobs, Vickery and Droge (2007) and Kumar, Garg and Garg (2009).
Early Supplier Involvement (ESI)	The intention is to maintain few suppliers and involve them from the beginning of the development and thus establish a long term partnership. The benefits are decreased risk, reduced costs and lead time, in addition to joint development and establishment of joint goals.	Gurumurthy and Kodali (2009), Salzman (2002), McAdam, Hazlett and Anderson-Gillespie (2008), Magnan, Fawcett and Birou (1999), Carr et al. (2008), Deros, Yusof and Salleh (2006), Ge and Fujimoto (2006), Williams (2007), Srai and Gregory (2008), Du (2007), Sarshar; Pitt (2009), Akesson, Jonsson and Edanius-Hällas (2007), Park et al. (2010) and Shamsuzzoha, Kyllönen and Helo (2009).
Standardization	Standardization is the basis for reducing the variables through the list of verifications and as a mechanism to capture knowledge. The standardization of the project involves the product, its components, raw material and its architecture. The standardization of processes involves common tasks, sequence and duration of tasks and the standardization of the technical abilities is related to the abilities of the people involved in the development team.	Emiliani (2008), Muenstermann et al. (2010), Marksberry et al. (2010), Wang and Kleiner (2005), Wee and Wu (2009), Gurumurthy and Kodali (2009), Rytter, Boer and Koch (2007), Kincade, Regan and Gibson (2007), Mohammed, Shankar and Banwet (2008), Reichhart and Holweg (2007), Summers and Scherpereel (2008), Grant and Banomyong (2010), Aláez-Aller and Longás-García (2010) and Nunes and Bennett (2010).
Integration/ Simultaneous Engineering	This signifies involving a multidisciplinary team from the beginning of the project to meet the requirements of the client at low cost. One of the main benefits is anticipating the already existing manufacturing and assembly problems and incorporating various fields of knowledge.	Du (2007), Kincade, Regan and Gibson (2007), Snee (2010), Arnheiter and Greenland (2008), Othman and Ghani (2008), Brousseau, Dimov and Setchi (2008), Tuholski et al. (2009), Saad and Gindy (2007), Arnheiter and Greenland (2008), Mottonen et al. (2009a), Dahlgaard-Park and Dahlgaard (2010) and Othman and Ghani (2008).
SBCE	In simultaneous engineering based on sets, each member of the development team communicates a set of parallel and independent alternatives until during the PDP phases, the alternatives are eliminated until the single best remains, generated from the combination of systems, subsystems and components.	Kincade, Regan and Gibson (2007), Schäfer and Sorensen (2010), Hines, Francis and Found (2006), Madhavaram and Appan (2010), Salah, Rahim and Carretero (2010), Doll, Hong and Nahm (2010), Mols (2010), Pêssoa, Loureiro and Alves (2007), Mottonen et al. (2009b), Joh and Mayfield (2009), Chin et al. (2010), Brousseau, Dimov and Setchi (2008), Gautam and Singh (2008) and Cooper and Edgett (2008).

Table 2. Continuation....

Item	Description	Authors
Virtual Simulation	To conduct virtual simulation through digital models (CAD/CAM and other modeling software). It is important for forecasting errors and interacting with the process, thus reducing costs of physical prototypes and time.	Ettlie and Elsenbach (2007), Fox et al. (2009), Sarkis, Talluri and Gunasekaran (2007), Bargelis, Kuosmanen and Stasiškis (2009), Saliba, Zarg and Borg (2010), Muglestone et al. (2008), Björnfot and Jongeling (2007), Grant and Banomyong (2010), Caputo and Pelagagge (2008), Reinsertsen (2007), Catalano et al. (2009), Linton and Walsh (2008) and Durmusogiu (2009).
Deployment Strategy	The corporate strategy is defined and broken down into individual objectives. Also called hoshin kanri, it is designed for the use of collective thinking to improve an organization's objectives in an aligned manner and with everyone's participation.	Sarshar and Pitt (2009), Gehlhar et al. (2009), Larsson, Arif and Aburas (2008), Sharif, Irani and Lloyd (2007), Nair and Boulton (2008), Parry, Milk and Turner (2010), Hofmann (2010), Taylor and Taylor (2008), Kaipia and Holmström (2007), Noori et al (2009), Byrne, Lubowe and Blitz (2007) and Wouters (2009).
Kaizen/ Continuous Improvement	This signifies improving continuously in a short space of time or at low cost, supported by a team brought together to achieve goals. It is based on PDCA and quality.	Smadi (2009), Taylor and Taylor (2008), Aoki (2008) and Badurdeen, Wijekoon and Marksberry (2011).
Performance Evaluation via Benchmarking	A continuous and systematic process to evaluate products, services and work processes at organizations that are recognized as representative of the best practices, with the goal of organizational improvement.	Christian-Carter (2002), Spendolini (1993), Camp (1989), Anand and Kodali, (2008), Waal and Counet (2009), Meybodi (2009), Miguel and Andrietta (2009), Huq, Abbo and Huq (2008), Gurumurthy and Kodali (2009), Quesada-Pineda and Gazo (2007), Sharma and Kodali (2008), Mottonen et al. (2009a) and Moffett, Anderson-Gillespie and McAdam (2008).

sector encompasses electrical appliances, motors and alternators, telecommunications devices, semiconductors, photographic equipment, computers watches and air conditioning. The auto-industry includes companies in the manufacturing sectors of weapons, automobiles, trucks, aerospace, automotive components, bicycles and airplanes. In the capital goods sector practical applications were found at companies that manufacture valves and solenoids, injected and molded plastics, rubber and machinery. These three sectors represent 50% of the sectors applied – electronics, (19%), auto-industry (18%) and capital goods (14%).

Concerning the location of the application, there were a total of 44. In addition to identification by country, applications that mentioned the continent were also included, such as Europe, North America, Asia and Africa. The country with the highest number of applications was the United States (18%), followed by the United Kingdom (15%), Sweden (7%), China (6%) and India (4%). Studies in Germany, Italy and Finland were each identified in publications, or 4% for each of them.

In terms of the year of publication, the most current were considered (from 2007 until August of 2011). Using as an example the Emerald Insight database, in which a search was conducted of the periodicals, Figure 3 shows that the theme has received increased attention, and is considered current and relevant among academics. In this period, there was a 35% increase in publications, an average of 10% per year.

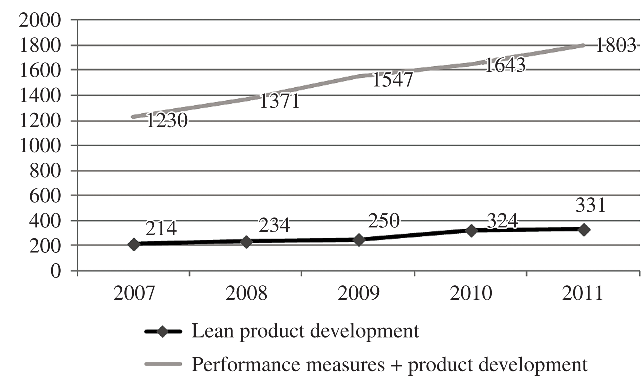

Figure 3. Growth in articles in academic journals from 2007 to 2011 (DAL FORNO, 2012).

3. Lean product development principles and practices

Before detailing the practices, it should be defined that "best practices" are those that have been shown to produce better results, selected by a systematic process, judged to be exemplary, good or successful (EFQM Benchmarking Manager apud JARRAR; ZAIRI, 2000).

In summary, good practices are techniques, methodologies, procedures or processes that were implemented and improve the results of a business for an organization, satisfying the needs of clients and interested parties. Meanwhile, a "best practice" is that which was proven to be the best approach by many organizations, based on the analysis of performance data for the process (JARRAR; ZAIRI, 2000).

This study will use the term "practices" as a synonym for "best practices." Table 2 defines some key terms used in this study related to the practices and principles of Lean Product Development.

Table 3. Lean Product Development Practices used in the publications analyzed (DAL FORNO, 2012).

Practice	Qty	%
Simultaneous Engineering/ Integration	94	12
Chief Engineer	60	7
ESI	99	12
Structural Organization	46	6
Visual Management	31	4
Modularity	62	8
Standardization	111	14
Learning network	103	13
SBCE	12	1
Virtual Simulation	35	4
VOC	116	14
VSM	39	5
Total	808	100

One of the main objectives of the classification of the studies was to identify which lean practices of the PDP were used, the indicators and the results. Table 3 thus highlights the most used practices considering that, many times, more than one was found in each study. Integration, Early Supplier Involvement, Standardization, Learning and the Voice of the Customer were the five practices that were most found. Later, these practices were explored in terms of concepts and results obtained with their introduction of PDP.

4. Conclusions

The lean approach has been a good alternative for improving product development processes to reduce time-to-market and deliver a product of value to the client. Many companies already use the practices in manufacturing and are expanding them to other areas of the company. Nevertheless, much still needs to be done because it is realized that the lean approach goes beyond the implementation of practices. An understanding of the principles and a visualization of the whole is needed, so that product development is visualized as a system that adds internal and external value. No company is totally lean or totally not lean. Even if the approach is not applied as a whole, some practices are initiated directly or indirectly.

The purpose of this paper was to explore the state of the art about product development, performance evaluation, the lean approach and their interfaces. The studies were evaluated with the main criteria of identifying the existing practices, the results that are being obtained with the introduction of lean product development, indicators that are being used and how this process is inserted in organizations.

Even with a large universe of studies explored since 2007 (nearly 300 articles), the gaps in the research are evident, that is, there are no clear metrics defined in a quantitative manner to diagnose PDP in the various industrial sectors. Thus, future studies are being undertaken to organize a diagnostic method via benchmarking to evaluate the degree of lean PDP at companies.

5. Acknowledgements

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