MATURITY ANALYSIS OF TAILOR BLANK WELDED TECHNOLOGY

Javier Zamora Carreño (jzamora@apm.com.mx),
Manufacturing Engineer, APM, division of IMSA-MEX, S.A. de C.V.
Noel León Rovira (noel.leon@itesm.mx) (Presenter)
Center for Innovation in Products and Technology, Tec de Monterrey, (CIDYT, ITESM)
Tel. +52 81 81582012, Ave. Eugenio Garza Sada #2501 Sur, Col. Tecnológico, 64849 Monterrey, NL, México

ABSTRACT

Tailor Welded Blank (TWB) Technologies have been extensively used for the design and manufacturing of car bodies over the last decade. In the last time this technology has started to be used for the design and manufacturing of automotive chassis. Cost analysis regarding the use of TWB in automotive frames does not allow extracting definitive conclusions concerning the convenience of introducing this technology.

The present paper describes the analysis performed regarding the convenience of introducing this technology for the design and manufacturing of automotive frames in one Mexican Enterprise.

TRIZ evolution patterns have been used for this analysis, especially the pattern 1 "Technology follows a life cycle of birth, growth, maturity, and decline".

More than 400 patents related to blank welding technologies were analyzed for identifying the maturity of this technology and positioning it along its S-curve. Minimal quadratic regression analysis was used to identify the shapes of the different life cycle curves.

INTRODUCTION

TWB Technologies have been extensively used for the design and manufacturing of car bodies over the last decade. A brief description of the frame follows for a better understanding of the final product in which the TWB Technology would be used.

Also known as "Ladder Frame", this kind of structure is the most frequently used in the light and heavy duty truck industry. The frame is composed mainly by three kinds of components:

1. Side members (SM): may be stamped, hydro formed or roll-formed. Their main task is to work as the skeleton of the vehicle.
2. Cross Members: Are perpendicular to the side members, they give torsion stiffness to the vehicle, and carry on some components. Although mainly stamped, sometimes they are hydro formed and roll formed.
3. Brackets: they serve as the links between the frame and the vehicle cabin, suspension, and also to carry some loose components. All of them are stamped.

The main duties of the frame are:

- Improve resistance and integrity to the vehicle, to allow heavy and light duty work.
- Help the suspension system by isolating shocks and forces in the cabin
- Protect the main cabin from crash impacts (Safety).

Fig 1 shows a typical truck frame.

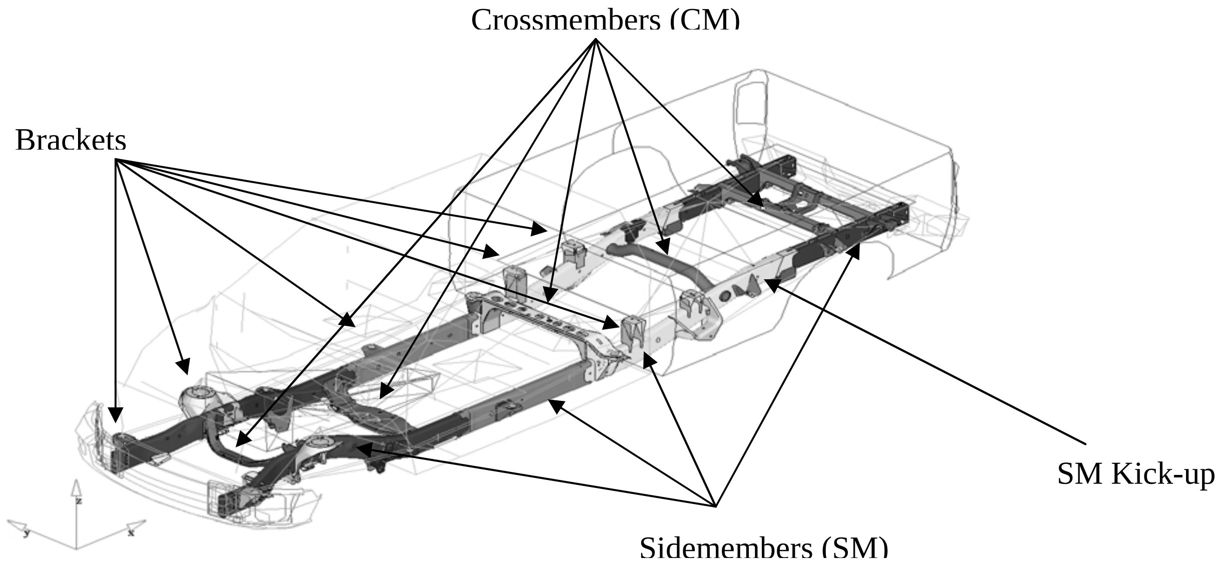

Figure 1 [1] : Typical Frame

The components are welded together mainly by MIG weld, although sometimes they are attached by bolts, or rivets. 80 % of the frame weight is due to the cross members and the side members [2].
TWB technology evolved rapidly in the "Body in White" area of the automotive business, driven by the need of reducing vehicle weight and increasing strength only in the required areas. As these drivers are also present in the frame, it is recommended to analyze this technology as an option. This work is focused on defining the economic impact and the status of the technology using TRIZ tools for identifying the potential of this technology the short and long term.
In order to do this, information regarding product development of the frame and the tailor blank technology, was gathered from journals, patent analysis, customers and suppliers feedback. For the economic analysis, cost evaluation methods and factors defined by Frame Industry were used.
TRIZ tools were used for analyzing the information from an integral point of view.

TAILOR BLANKS / TUBES

Although TWB is not new for the automotive industry, it is yet relatively unknown for truck frames. TWB is mainly used in the "Body in White" area for joining metal sheets of different thickness and/or properties through laser welding. Those welded sheets are later formed by stamping or hydro forming. This way, resistance is increased only in the areas required without increasing weight or cost [3, 8, 18, 29, 30]
This concept is currently also applied in the structural stamped components located near the main cabin, especially in places where controlled energy absorption is required in case of an impact.
With the new safety regulations on the truck industry, the truck frames need not only to keep doing their usual duties, but also they have to be involved in the safety task of energy absorption during crash impact.[18, 19]
Furthermore, customers seek to reduce weight in the vehicle for increasing the pay load and for reducing the fuel consumption.[18, 19]

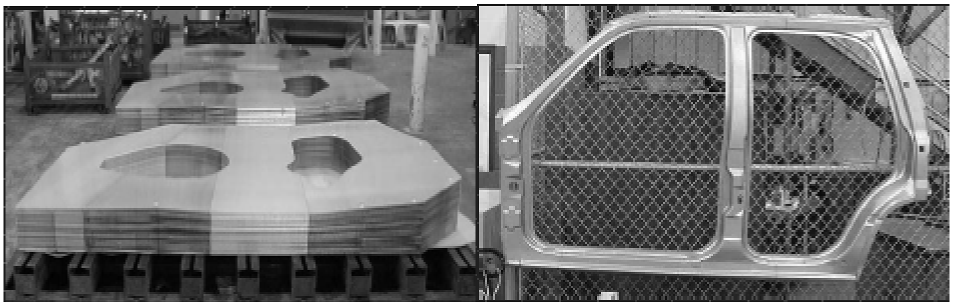

Figure 2[29]: Tailor Weldled Blank Examples in automotive bodies

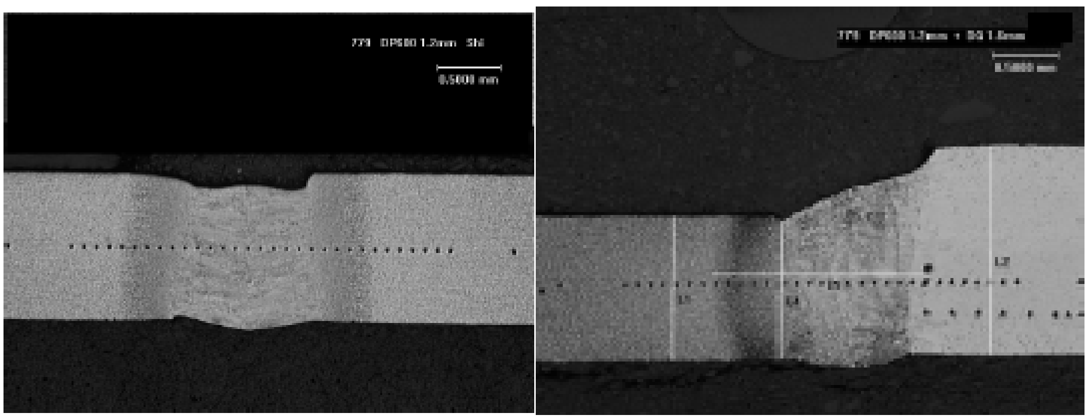

Figure 3[18]: Typical Tailor Blank welding

TWB uses laser welding to avoid increasing weight in the resulting blank. It is also the only welding process that reduces the heat affected zone to a minimum and it is also convenient for welding different types of steel.
The disadvantage is that it requires high quality edges that are not usually accomplished in typical blanking processes and therefore edge preparation processes are required. For Tailor Tubes, a process and equipment are required that forms the plate to tubes and later the edges are welded to “close” the tube. As in the TWB process, the edges to be welded require also special preparation.

Figure 4[6, 16]: Tubes made with Tailor Tube Process

TRIZ PATTERNS OF EVOLUTION

TRIZ Patterns of Evolution help in finding the status and future development of a given technology. Altshuller recognized 8 of technological evolution:

	Pattern
1.	Technology follows a life cycle of birth, growth, maturity, and decline.
2.	Increasing Ideality.
3.	Uneven development of subsystems resulting in contradictions.
4.	Increasing dynamism and controllability.
5.	Increasing complexity, followed by simplicity through integration.
6.	Matching and mismatching of parts.
7.	Transition from macrosystems to microsystems using energy fields to achieve better performance or control.
8.	Decreasing human involvement with increasing automation.

Table 1: Technological Patterns of Evolution

The first three patterns will be used for identifying the evolution stage of the technology and for visualizing the future development of the truck frames.

Technology Maturity Mapping

To define in which stage of its S-curve is situated TWB technology, 4 descriptive curves are used, as shown in the following Figure

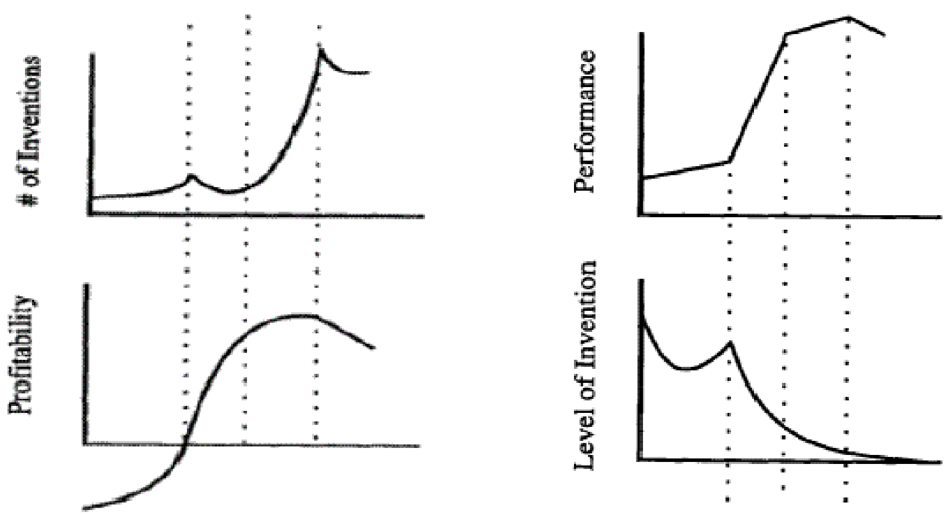

Figure 5[25]: S-Curve Descriptors.

A patent research was made using the US Patents Office, starting in year1976 when the first patent related to joining sheets with different thickness or properties was issued until present.
The key concepts for the patent search were the following:

- Laser butt-welding of metallic materials
    - Different mechanical properties
    - Different thicknesses.
- Laser butt-welding
- Sheet Edge-Preparation for laser welding.
- Laser welding systems.
- Material handling for laser welding.
- Tailor Weld.
- Laser butt-welding inspection systems.

A total of 421 patents were found in a first search. After further analysis, only the patents related to concepts applied in TWB equipment were used. That reduced the number of patents to 132 (See Annex). From these patents the following graphics were built:

Number of Patents (Inventions) vs. Time.

Two graphics were drawn, the first one showing the amount of patents every 5 years, and the second showing the amount of patents per year. The intention was to identify if the patterns remain under different curve construction criteria. A quadratic regression was calculated in order to mathematically identify the pattern behavior vs. time.
The main difference between both graphics is that the five-year curve loses the first peak effect due to its accumulative nature. Comparing the shape of both curves against the reference descriptor suggests that this technology is located in its first stage of evolution. Although it also looks as if the resulting graphic may be placed in stages 2 and 4 of the reference descriptor, this was discarded as the plot starts since the first patent related to this technology was found.

Performance vs. Time

Due to non available reliable information regarding a variable that reflects the performance (welding speed, equipment performance, etc), this graphic will not be plotted at this time, hoping that the remaining patterns will give us an insight of the location of the technology performance in its S-curve.

Profitability vs. Time

The amount of TWB sold per year in the automotive industry was used as criteria of technology profitability. The sales were tracked starting 1993 (before that year, only two vehicles had TWB). The graphic shows the sales in USA, and in Europe.

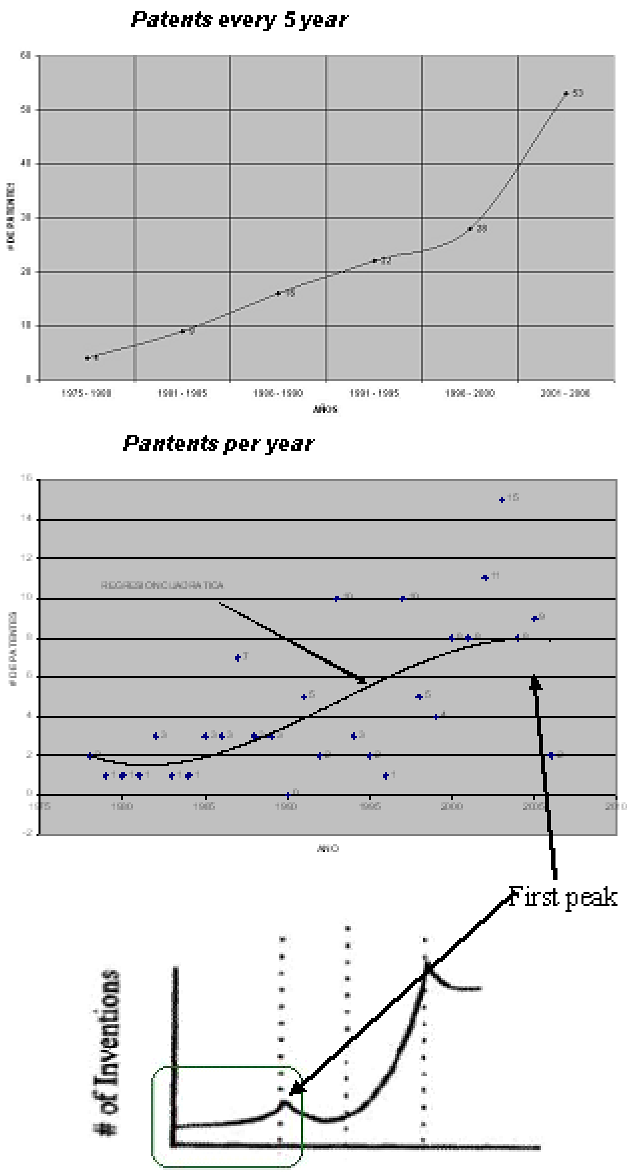

Figure 6: Number of Inventions vs. Time descriptor

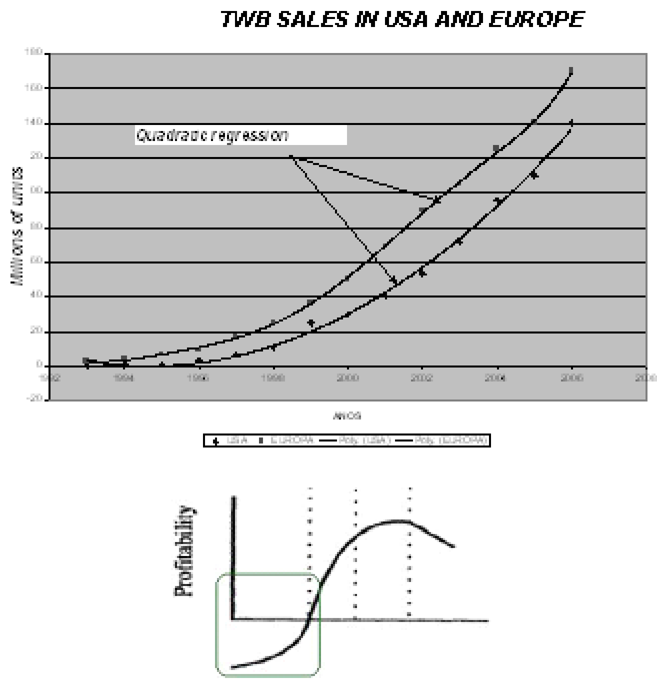

Figure 7: Profitability vs. Time

Comparing the resulting graphic versus the profitability pattern, we find that its shape also falls in the first stage of the curve.

Level of Invention vs. Time.

For this graphic, each one of the 132 patents was evaluated. A value of level of invention from 1 to 5 was assigned, according to the following:
Level 1: Standard solution;
Level 2: Change in the system;
Level 3: Innovation;
Level 4: Invention;
Level 5: Discovery.
This evaluation was made by persons with expertise in manufacturing and sales of TWB , and people that manufacture and sell equipment for TWB, and the authors of this document. The results per year shown in the graphic is the average of the values assigned to each patent.

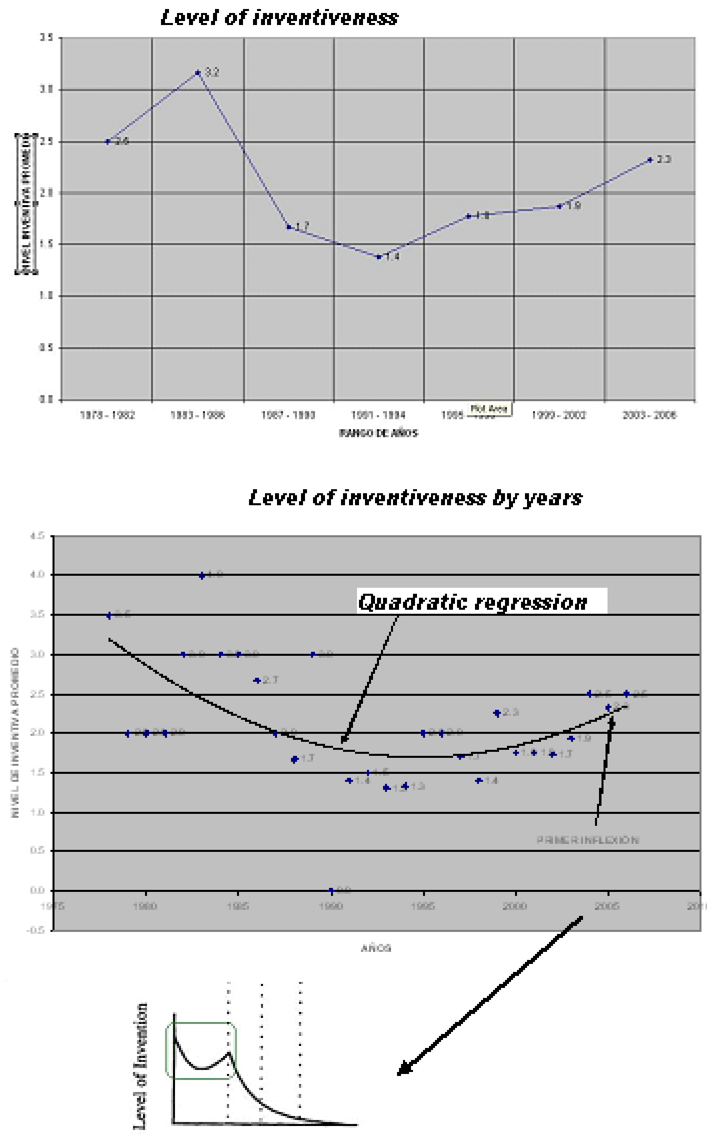

Figure 8: Level of Inventions vs. Time

As in the case of the number of patents, two graphics were drawn, the first one showing the level of inventiveness of patents every 5 years (the average of the five years), and the second showing the amount of patents per year (the average in the level of invention from that year's patents). A quadratic regression was also plotted in this case.

The resulting graphics show curves that falls and rises again (two peaks), typical behavior of the first stage of development in the level of invention

Summarizing the result obtained in the three graphics of patent and market analysis may be inferred that this technology is just starting to get into its growth stage.

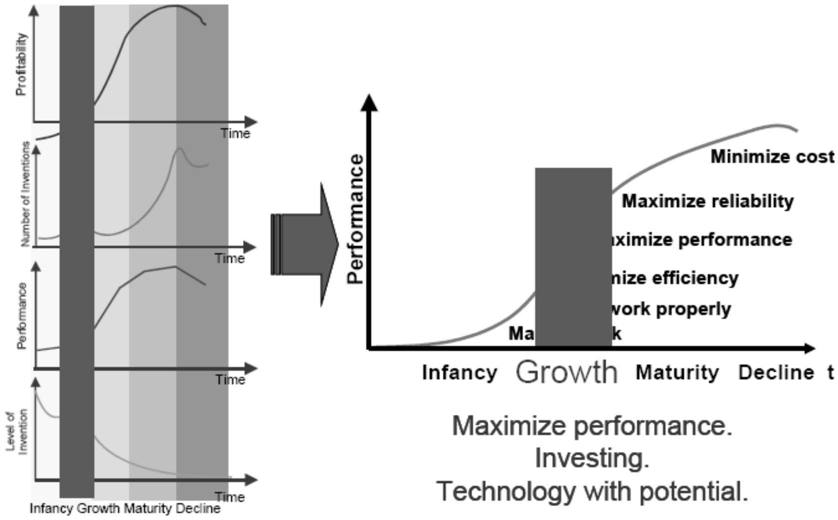

Figure 9[21]: Location in the S-Curve

These results allow concluding that the performance pattern is also in growth stage.
As TWB is currently entering its growth stage, and the cost study found savings and advantages regarding flexibility, weight savings and performance improvements, this technology becomes an attractive option.
However, it is still necessary to find out if this is the best technology available in the automotive industry for new investments. In order to identify that issue, the pattern of Increasing Ideality and the concept of Final Ideal Result were used.

Increasing Ideality

First, we have to identify the advantages that this technology delivers, as well as its disadvantages.
Advantages:

- It does not require adding material as in MIG weld, reducing weight.
- Reduced part numbers in the assembly, allowing logistics savings.
- Less tooling (Less press time, set-ups, and sub-assembly area)
- Allows welding different types of steels.
- Reduces weight by avoiding overlaps as required in MIG welding.
- It has better forming capabilities for tubes (6 – 8%),
- Tubes can be made conical, or with variable diameters.
- Strength where it is really needed.
- Flexible.

Disadvantages:

- Requires investment in specialized expensive equipment.
- Laser technology is not common in Mexico
- Edge preparation required
- Maximum thickness allowed is 3 mm, while up to 5 mm is required sometimes.
- Slow process for tube manufacturing

An ideal solution would be a technology that allows welding metal sheets of different thicknesses and/or properties with traditional equipments, without laser or any kind of welding, that does not require special re-works of the edges to be welded, or even it does not need to weld edges. It should also allow working with thicknesses bigger than 3 mm and is highly productive.
After some research, a couple of processes were found that, even though they do not process exactly the same kind of product, their goals are similar to the ones of the TWB.

Structural Foam

Injected foam is used to absorb energy in crash impact situations, to provide higher stiffness to automotive structures with lesser weight increase than steel. Injector foam also avoids investment in tooling and presses. It does not require welding processes and is flexible for engineering changes. It is widely used in the "Body in White" area of the automotive industry and it can be applied to any kind of metal.

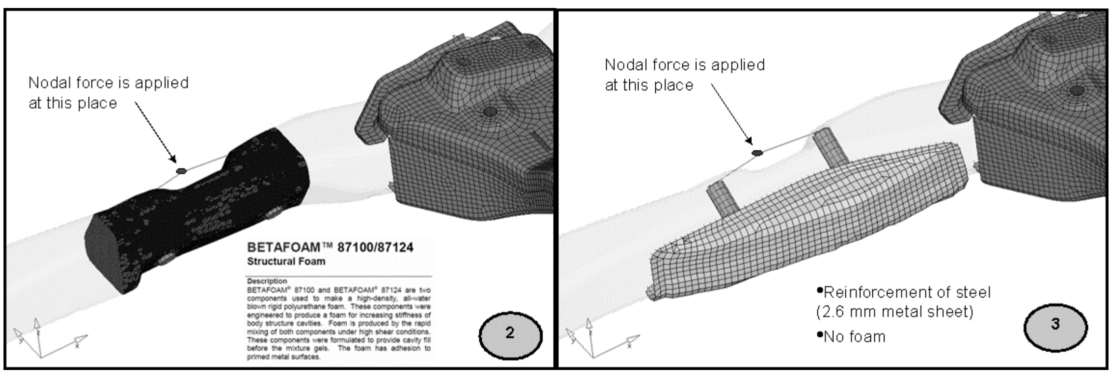

Figure 10[2]: Use of foam.

The problem with this option is that in some cases the material is very expensive (severe duty cases) and it can be applied only in small hollow areas. It can not be used in open areas. Furthermore, it requires special care in the assembly process, due to its flammable nature.

Tailor Rolled Blanks

This option does exactly the same as TWB, but without welding. It does not require non value adding processes as edge-preparation in the TWB. This technology is performed in the milling process of the steel plate, where the roll-forming rods from the mill are CNC controlled for changing the thickness of the sheets according to the desired pattern.

Figure 11[5, 35]: Tailor Rolled Blanks production process.

The main limitations for this technology are related to its size limits as the maximum width of the plate is 1400 mm. It may only process mild and high strength low alloy steel. The transition between thicknesses requires at least 10 mm, which affects weight and performance issues in the vehicle.

This exercise helped us identifying other technologies that eliminate some problems from TWB, but also shows other limitations that the TWB has already overcome. Thank to this, we know now where to focus the development of the TWB. It also allowed us to realize that these other technologies may overcome their limitations in the future, and become a competitor for TWB. It is recommended to analyze both technologies further, to locate them in the S-curve, relative to the one of the TWB.

Uneven development of subsystems resulting in contradictions.

This analysis is based on the review of the TWB patents, the market study, and the analysis of performance evolution of TWB. The goal is to define if the future of this technology and the future of the truck frame collide in some point.

A table was made with 4 columns and at least three rows. In the rows we list what is known as Supersystem, System and Subsystem. The System is the process or technology to review; the Supersystem is where the system (i.e. TWB) is applied, in this case, the frame; and the Subsytem are the different components of the TWB process, preferably critical elements.

The columns separate the information in Past, Present & Future. After an analysis of the information gathered from the past and present of the systems, a future scenario is projected, based in the market study and the current limitations.

	Past	Present	Future
Super-system	**Open Frame**	**Closed Frame**	**Unibody, structural Frame (Ridgeline, Cayenne/Tuareg)**
	All Vehicles (Cars, PU Trucks)	Pick-up trucks, SUV's	Pick-up Trucks, Crossovers
	Stamping, MIG, Wax Paint. In-Line Assembly	Stamping, Hydro forming, Roll forming, CNC Bending, Laser cut, Machining centers, MIG Welding, E-coat	Stamping, Hot gas forming & Stamping, Roll forming, CNC Bending, Laser cut, Laser welding & Machining, friction

		paint In-Line Assembly	weld, spot weld, Tailor blank Modular/Flexible Assembly
	1010/1008 Steels	1010/1008 Steels, HSLA, Tubes.	UHSS/AHSS Steels (Dual phase, TRIP, TWIP, X-IP Boron). Aluminum, Composites
	Many Frame models, Many Vehicles	One Frame, Many models and vehicles	No Frames, each model has its own structural design
System	**TWB Mash Seam**	**TWB Laser**	**TRB, Structural Foam, Remote Laser/ Adhesives**
	Overlap Joint	Butt Joint	No Joint
	Slow Process, One weld	Fast process, several welds.	Several welding at different location at a time.
	Thin Material.	3 mm max.	No limit
	Mild steel only, similar thicknesses	UHSS steel, aluminum, Different thicknesses and properties	Composites.
	Only Plates	Plates & Tubes	Full vehicle assembly
Subsystem	Electricity/ MIG	Laser	Adhesives, Synthetic reinforcements.
	Selective destructive tests, outside production line.	Non- Destructive In-Line Inspection 100%.	100% reliability.
	Linear welding, one axle only.	Curve welding, three axles.	6 axles, assembly zone.
	Material added	No material added	No process required.
	Low power, low accuracy.	High Power, High accuracy.	Low Power, High Accuracy
	Overlapping required	Edge-preparation required	No overlapping or edge preparation required

Table 2: Patterns of Evolution Matrix: Tailor Blank $_{[1 – 20, 23, 28 – 31]}$

According to the market research, the main drivers of the changes regarding the frame design are:

- Safety: Cars already have 20 years meeting safety requirements and TWB meets this driver. Pick-up trucks are just starting to accomplish these safety aspects drawing technologies as hydro forming and TWB to comply.
- Environment: The fuel consumption goal for pick-up trucks in 2007 is 22.2 miles per gallon, pushing OEMs to find ways to reduce weight without sacrificing safety.
- *Performance*: Customers have become well informed regarding automotive vehicles, and want pick-ups that not only support the off road duties, but that are also comfortable and fun to drive on the roads. This is driving the design of the frame towards the unibody type of structure that is typical for cars but with high strength reinforcements that may be easily achieved with TWB. The following figures show examples of SUVs and pick-ups trucks with this kind of structure (Ridgeline from Honda, and the Cayenne/Tuareg from Porsche/VW)

Figure 12[18, 20].-RIDGELINE (HONDA)

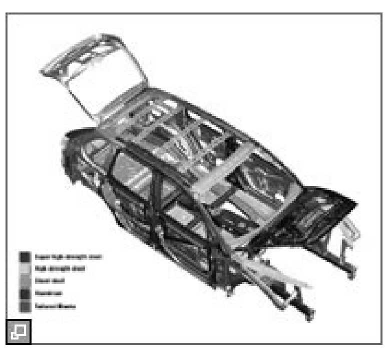

Figure 13[18, 20].- CAYENNE/TUAREG (PORSCHE/VW)

The pick ups of figures 12 and 13 intensively use TWB.
The trends of the TWB process are towards efficiency, safety, reliability and flexibility. That is typical of technologies entering into the Growth stage. The main drivers are profitability and attractiveness for the customer.
Table 2 shows that the System and Subsystems are ahead of the Supersystem (the frame), as TWB evolved primarily for the cars industry due to safety reasons.
From the future scenarios shown in the table, and the market study, we define a future scenario for the frame and the TWB:

- The frames will suffer radical design changes regarding:
    - Materials (Thin, Ultra High Strength Steels, with different microstructure)
    - Joining processes (Due to new materials)
    - Assembly processes (Due to new joining processes)
    - Volumes and models.
- Some products will not use frames, but unibodies.
- Both choices will certainly use TWB because:
    - They will use steels whose performance depends on laser welding (reduced heat affected zone)
    - It is currently used in unibodies and spaceframes manufacturing, where thinner sheets are used.
    - The technology will keep improving, and will allow a wider variety of thicknesses to be welded
    - The pressure regarding fuel consumption ad safety improvement will continue increasing.
- Other Technologies will grow enough to compete against TWB in areas they currently can not today.
    - Foams will become lighter, stronger and cheaper.
    - The Tailor Rolled Blank process will increase the width of coils they can handle, and will expand to us higher strength steels (UHSS).
    - This will take several years, because these technologies are not yet as well grounded in the automotive industry as the TWB

CONCLUSIONS

At the first stage of this study, was concluded that it is convenient to introduce TWB technology in Mexico, whether buying own equipment or through association with a current TW**B** manufacture provider. Although only small savings in stamping will be achieved considerable savings in hydroforming and in weight reduction thanks to smarter use of material justify this decision.
At the second stage of the study this idea was further reinforced because the technology is entering in its growth stage ant that means that further possibilities for continue improving the technology will arise.
Through the patterns of evolution was found that the future of the frames is heading to the intensive use of UHSS that will lead to structures totally different to the current ones, whose joining techniques will require the use of technologies already proven in the Tailor Blank, making the MIG obsolete in several areas.

However we have to keep an eye on potential substitute technologies for TBW, keeping in mind that technologies today have shorter life cycles.
The design trends of SUV's and pick-ups will move towards the intensive use of UHSS leading to reduced sheet thicknesses, that will make the use of MIG welding practically impossible.
Summarizing, TWB is critical for the future of truck frame Industry, due to market trends regarding safety, fuel consumption, and customer satisfaction.

This paper has been funded by the Research Program Creativity, Inventiveness and Innovation in Engineering Education (CAT043) from Tecnológico de Monterrey, Campus Monterrey and was performed as the Master Thesis from one of the authors supported by Metalsa.
The authors thank Technológico de Monterrey and Metalsa for the support.

REFERENCES

1) www.metalsa.com.mx
2) Intramet (Internal network, Metalsa)
3) Tailored blanks come on strong. Automotive Manufacturing & Production, May, 1997 by Al Wrigley
4) http://www.a-sp.org/database/custom/twbmanual/printsection.asp?hid=9
5) www.corusgroup.com
6) www.soudronic.com
7) Tailor Welding in Europe. By David. A. Belforte. http://ils.pennnet.com/Articles/Article_Display.cfm?Section=Archives&Subsection=Display&ARTICLE_ID=149692
8) www.worldautosteel.org
9) www.ulsab-avc.org
10) www.servorobot.com
11) http://www.getec.etsit.upm.es/docencia/gtecnologia/gtecnologia.htm
12) http://www.triz-journal.com/.
13) www.dow.com
14) www.noble.com
15) www.waynetrail.com
16) www.weil-engineering.de
17) www.automotivenews.com
18) Dual Phase Steel Applications in Tailor Welded Blank Technology. Alex A. Konieczny. www.autosteel.org
19) Applications of AHSS & Hot Stampings in Automotive Structures. Frank A. Horton. Arcelor Auto Symposium, Cannes 2005
20) The Frame of the Future? Christopher A. Sawyer. Automotive Design & Production, Enero 2004.
21) TRIZ on Rapid Prototyping: -a case study for technology foresight. Jörg Stelzner, Carlos Palacios, Tobias Swaton
22) The Application of TRIZ to Technology Forecasting. A Case Study: Brassiere Strap Technology. Kim Lovel, Chad Seastrunk, Timothy Clapp. College of Textiles, North Carolina State University, Raleigh, USA

23) Study of Effective New Product Development Activities through Combination of Patterns of Evolution of Technological Systems and VE. THE SANNO INSTITUTE OF MANAGEMENT. Senior Researcher, Manabu Sawaguchi. March 2001.
24) Strategic TRIZ and Tactical TRIZ: Using the Technology Evolution Tools. Ellen Domb. This article was first published in Izobretenia, The Journal of the Altshuller Institute, October, 1999.
25) Application of TRIZ to Technology Forecasting. Case Study: Yarn Spinning Technology. Severine Gahide. http://www4.ncsu.edu/~sgahide/cv.html
26) The Determination of the Technological Maturity of Ultrasonic Welding. Nathan Gibson
TE 589A. North Carolina State University. April 29, 1999
27) Using S-Curves and Trends of Evolution in R&D Strategy Planning. Darrell Mann Industrial Fellow, Department Of Mechanical Engineering, University Of Bath, Bath, UK
28) The Future of Forming and Fabricating Technologies. SME/AFFT. March 2003
29) Laser Blank Welding: A Global Perspective. Bob Lewinski. October 2001
30) The Trends of Steel Products in the European Automotive Industry. M. Jenneau, P. Pichant. La Révue de Métallurgie. November 2000.
31) Characterizing Aluminum Tailor Welded Blanksfor Automotive Applications. R.W. Davies, H.E. Oliver, M.T. Smith, and G.J. Grant. JOM, November 1999
32) Transnational Management. Bartlett, Ghoshal & Birkinshaw. McGraw Hill, Fifth Edition, pages. 216 & 266
33) Corporate Strategy: Resources & the Scope of the Firm. Collis Montgomery. McGraw Hill. page 635.
34) Product Design. Kevin Otto & Kristin Wood. Prentice Hall,
35) Quotes from the following suppliers:
    - TWB, Coros, Soudronic, Noble Metal Processing., Arcelor, Dofasco, VIL,WEIL
36) www.uspto.gov

Annex
LIST OF PATENTS USED IN THE STUDY[36]

PATENT #	NAME	DATE	LEVEL OF INVENTION
4,121,087	Laser welding	17-Oct-78	4
4,127,761	Method and apparatus for controlling laser welding	28-Nov-78	3
4,162,390	Laser welding chamber	24-Jul-79	2
4,237,364	Welding tool and method	2-Dec-80	2
4,326,118	Laser beam welding apparatus	20-Apr-82	3
4,330,699	Laser/ultrasonic welding technique	18-May-82	4
4,358,658	Laser weld jig	9-Nov-82	2
4,419,562	Nondestructive real-time method for monitoring the quality of a weld	6-Dec-83	4
4,461,946	Apparatus for clamping an assembly of parts for laser welding	24-Jul-84	3
4,501,950	Adaptive welding system	26-Feb-85	4
4,514,613	Method of an apparatus for welding together metal components	30-Apr-85	3
4,527,040	Method of laser welding	2-Jul-85	2
4,577,088	Method of laser butt welding	18-Mar-86	3
4,626,651	Apparatus for butt welding steel strips by using a laser beam in a steel strip-processing line	2-Dec-86	2
4,633,057	Laser welder fault detector	30-Dec-86	3
4,634,832	Laser-beamwelding	6-Jan-87	3
4,644,129	Apparatus and method for edge welding sheet metal	17-Feb-87	2
4,658,110	Method and apparatus for welding	14-Apr-87	2
4,682,002	Method of laser welding sheet metal protected by low-vaporizing-temperature materials	21-Jul-87	2
4,684,779	Laser welding metal sheets with associated trapped gases	4-Aug-87	1
4,694,137	Laser welding head for sleeve-to-tube welding	15-Sep-87	2
4,737,612	Method of welding	12-Apr-88	2
4,751,365	Method for butt welding two pieces of different metal, particularly pieces of medium or high carbon content steel, with a laser beam	14-Jun-88	2
4,831,233	Optically controlled welding system	16-May-89	4
4,835,357	Sheet metal laser welding	30-May-89	2
4,855,564	Laser beam alignment and transport system	8-Aug-89	3
4,988,845	Device to cut and butt-weld bands or metal sheets having limited dimensions	29-Jan-91	1
4,992,643	Method and device for controlling plume during laser welding	12-Feb-91	1
4,995,087	Machine vision system	19-Feb-91	2
5,038,016	Laser welding monitoring system and method	6-Aug-91	2
5,049,720	Laser welding apparatus with sky window	17-Sep-91	1
5,142,119	Laser welding of galvanized steel	25-Aug-92	1
5,147,999	Laser welding device	15-Sep-92	2
5,179,261	Split beam laser welding system	12-Jan-93	1
5,183,992	Laser welding method	2-Feb-93	2
5,187,346	Laser welding method	16-Feb-93	2
5,190,204	Laser butt-welding device and method	2-Mar-93	1
5,190,207	Method for welding rectangular tubes	2-Mar-93	1
5,245,156	Method of laser-welding metal sheets having different thicknesses	14-Sep-93	1
5,249,727	Weld penetration depth inspection	5-Oct-93	1
5,250,783	Method of laser-welding metal sheets having different thickness	5-Oct-93	1
5,264,678	Weld-bead profilometer	23-Nov-93	1
5,268,556	Laser welding methods	7-Dec-93	2

PATENT #	NAME	DATE	LEVEL OF INVENTION
5,324,913	Method and apparatus for laser welding	28-Jun-94	1
5,343,010	Process for seam welding of sheet metal blanks	30-Aug-94	1
5,371,337	Welding process and apparatus	6-Dec-94	2
5,389,761	Method and apparatus for cleaning metal pieces prior to resistive seam welding or laser lap seam welding	14-Feb-95	2
5,451,742	Laser welding method	19-Sep-95	2
5,519,184	Reusable laser welded hermetic enclosure and method	21-May-96	2
5,591,358	Apparatus for clamping and laser welding	7-Jan-97	1
5,591,360	Method of butt welding	7-Jan-97	1
5,595,670	Method of high speed high power welding	21-Jan-97	3
5,601,736	Butt welding process using high density energy beam	11-Feb-97	2
5,624,585	Method and apparatus for welding material by laser beam	29-Apr-97	1
5,630,269	Method for fixturing abutted sheet metal parts for welding	20-May-97	1
5,648,619	Arrangement for inspection of welded plate sections	15-Jul-97	1
5,651,903	Method and apparatus for evaluating laser welding	29-Jul-97	2
5,674,415	Method and apparatus for real time weld monitoring	7-Oct-97	3
5,681,490	Laser weld quality monitoring system	28-Oct-97	2
5,760,365	Narrow gap laser welding	2-Jun-98	1
5,780,802	Process for machining and butt-welding at least one edge of a sheet metal plate	14-Jul-98	1
5,814,786	System and method for laser butt-welding	29-Sep-98	2
5,823,417	Laser pressure foot	20-Oct-98	2
5,859,402	Process for the welding of work pieces with laser beams	12-Jan-99	2
5,941,110	Adaptive method and apparatus for forming tailor welded blanks	24-Aug-99	2
5,951,889	System and method for laser welding	14-Sep-99	2
5,961,859	Method and apparatus for monitoring laser weld quality via plasma size measurements	5-Oct-99	3
6,010,182	Vehicle chassis and body construction	4-Jan-00	3
6,023,044	Control method in multi-layer welding	8-Feb-00	1
6,024,273	Method and system for determining weld bead quality	15-Feb-00	3
6,034,343	Hybrid welding apparatus	7-Mar-00	2
6,060,685	Method for monitoring laser weld quality via plasma light intensity measurements	9-May-00	2
6,087,619	Dual intensity multi-beam welding system	11-Jul-00	2
6,116,829	Apparatus for machining at least one edge of at least one sheet metal plate	12-Sep-00	1
6,140,601	Laser-welded steel pipe and method therefore	31-Oct-00	1
6,153,853	Laser beam welding apparatus	28-Nov-00	2
6,184,987	Process for detecting and correcting a misalignment between a fiber cable and a light source within a fiber module	6-Feb-01	3
6,188,041	Method and apparatus for real-time weld process monitoring in a pulsed laser welding	13-Feb-01	2
6,211,483	Multiple beam laser welding apparatus	3-Apr-01	2
20010008231	Apparatus and control system for laser welding	19-Jul-01	1
6,281,472	Method and process gas for laser welding metal workpieces	28-Aug-01	1
6,288,359	Welding device for two work pieces to be joined together by a weld seam which is closed in itself	11-Sep-01	1
6,308,882	Method for joining ductile iron and steel	30-Oct-01	1
6,329,635	Methods for weld monitoring and laser heat treatment monitoring	11-Dec-01	2

PATENT #	NAME	DATE	INVENTION
20020008089	Light guide for laser welding	24-Jan-02	2
6,344,625	Method and apparatus for monitoring the size variation and the focus shift of a weld pool in laser welding	5-Feb-02	2
6,399,915	Method and apparatus for determining quality of welding at weld between working material pieces	4-Jun-02	3
6,403,918	Laser welding system	11-Jun-02	2
6,416,051	Sheet guiding device and method of production	9-Jul-02	1
6,441,335	Process for beam-welding two members different in hardness	27-Aug-02	2
6,444,947	Method and device for laser beam welding	3-Sep-02	2
6,452,131	Apparatus and control system for laser welding	17-Sep-02	1
6,453,752	Fixture for testing shear strength in tailor welded blanks	24-Sep-02	2
6,455,803	Laser welding system	24-Sep-02	1
6,462,299	Method of joining strips in a steel strip continuous processing line	8-Oct-02	2
6,479,786	Laser welding system	12-Nov-02	1
6,521,861	Method and apparatus for increasing welding rate for high aspect ratio welds	18-Feb-03	3
6,528,755	Light guide for laser welding	4-Mar-03	1
6,528,756	Laser lap welding process of welding together overlapped plated steel sheets	4-Mar-03	2
6,531,675	Laser welding method and apparatus	11-Mar-03	2
6,555,780	Method for monitoring the size variation and the focus shift of a weld pool in laser welding	29-Apr-03	3
6,563,073	Method of welding metals and apparatus for use therefor	13-May-03	1
6,603,092	Hybrid electric-arc/laser welding process, especially for the welding of pipes or motor-vehicle components	5-Aug-03	2
6,608,285	Hybrid arc/laser welding with earth contactor position control	19-Aug-03	2
6,633,018	Laser welding head with associated roller	14-Oct-03	1
6,642,474	Process for the production of multi-thickness and/or multi-material blanks	4-Nov-03	1
6,646,225	Method of joining galvanized steel parts using lasers	11-Nov-03	2
6,657,156	Laser welding method and laser welding apparatus	2-Dec-03	1
6,669,379	Method of attaching optical fiber in alignment with a light source in an optical module	30-Dec-03	3
6,670,574	Laser weld monitor	30-Dec-03	1
6,683,268	Application of a hybrid arc/laser process to the welding of pipe	27-Jan-04	2
6,713,713	Lens to adapt laser intensity for uniform welding	30-Mar-04	4
6,750,421	Method and system for laser welding	15-Jun-04	2
6,770,840	Method of butt-welding hot-rolled steel materials by laser beam and apparatus therefor	3-Aug-04	2
6,803,538	Laser welding system	12-Oct-04	1
6,807,218	Laser module and optical subassembly	19-Oct-04	3
6,815,635	Use of helium/nitrogen gas mixtures for laser welding tailored blanks	9-Nov-04	3
6,818,857	Method and apparatus for welding	16-Nov-04	3
6,825,442	Tailor welded blank for fluid forming operation	30-Nov-04	2
6,852,945	Laser welding boiler tube wall panels	8-Feb-05	1
6,861,611	Weld checking apparatus for laser welding machine	1-Mar-05	2
6,875,949	Method of welding titanium and titanium based alloys to ferrous metals	5-Apr-05	3
6,900,410	Laser welding processed	31-May-05	1
6,906,281	Method for laser welding of metal	14-Jun-05	2
6,937,329	Method for detecting and identifying defects in a laser beam weld seam	30-Aug-05	3
6,940,036	Laser-plasma hybrid welding method	6-Sep-05	4

PATENT #	NAME	DATE	INVENTION
20050200164	Automotive vehicle body having tailor welded blanks	15-Sep-05	2
6,957,848	Engineered welded blank	25-Oct-05	2
6,965,091	Pressing device	15-Nov-05	3
6,998,569	Apparatus and method for regulating the weld seam position during laser welding of a butt-jointed workpiece	14-Feb-06	3
20060034580	Waveguide apparatus and method for laser welding	16-Feb-06	2