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A Reasoned Evolutionary Study on the Actual Design of Farm Tractors

Marco Bietresato¹  [0000-0002-6166-8958] and Fabrizio Mazzetto¹[0000-0001-9272-277X]

¹ Faculty of Science and Technology, Free University of Bolzano,
piazza Università 5, 39100 Bolzano, Italy
marco.bietresato@unibz.it

Abstract. In some industrial sectors, such as the one concerning the manufacturing of agricultural machinery (farm tractors in particular), most recent innovations focus on improving specific technical sub-systems considered more or less strategic by manufacturers, end users or legislators, for example the engine (with the introduction of increasingly-efficient pollution-abatement systems) or the three-point hitch (with new controllers able to automatically adjust the operating height, thus maintaining a constant traction-effort on the tractor while tilling). The level of scale/detail, at which the three above-mentioned stakeholders are concentrating nowadays, is undoubtedly an indication of an industrially-mature product and, therefore, with a configuration optimised for the purposes it is intended to serve, but improvable on individual isolated subsystems. In reality, what we call “farm tractor” is the result of an evolutionary process that has led the current configuration to prevail in numerical terms over other proposals that have been made throughout the history, not necessarily worse on a technical level but certainly losing out on an economic level. It is an example of the so-called “dominant design”. In this article, the evolutionary history that has led the farm tractor to its current configuration(s) will be retraced, and explicit technical justifications will be given for the solutions that are currently adopted. The final aim of this study is: (1) understanding whether the motivations that led to the current design still exist and, in case, (2) individuating some novel or, even, simply forgotten design-solutions, which deserve to be present in the farm tractor of the future, possibly hybrid or robotic.

Keywords: Farm Tractor, Macroscopic Configuration, Evolutionary Trends, Dominant Design.

1 Introduction

1.1 An Evolutionary Point of View for Technical Systems

The Darwin’s basic scheme of *variation*, *selection* and *inheritance* originally developed by observing the evolution of living beings, can be applied also to the evolutionary processes that can be experienced in domains different from the original biological-ecological ambit, as observed by Hull and Dennett in their respective studies [1, 2], including also artificial systems. It is so possible to refer to this as a “universal” or

“generalized” Darwinism applied to *evolutionary systems*. Indeed, it is possible to observe that also many artificial systems undergo an evolution involving their shape and technical features, model after model exactly as it is observable for natural systems generation after generation of individuals. Continuing in the similitude with living beings, the design of a technical system can also evolve according to the principles of *differentiation* (from a previous common design) and *similarity* (to other technical systems), which are followed more or less consciously by designers and engineers to satisfy the ever-new requests from the customers (e.g., new product functionalities), the lawmakers (e.g., new safety/anti-pollution requirements) and the marketing department (e.g., a product repositioning or new competitors) [3]. To achieve this task, some authors suggested to use, for example, the modular-design and the parametric-design concepts [4], or even other design tools [5] applied since the very concept of the system, to create also an artefact family [6]. From a conceptual point of view, however, the most ground-breaking and effective approach is certainly represented by the TRIZ, formalised by G. Altshuller in 1984 [7]. This latter methodology is also particularly effective in describing the evolution undertaken by systems till arriving to their actual stage, thanks to specific tools (*Evolutionary Trends* and *Technology “S” Curves*). However, from a descriptive-only point of view (i.e., without any pretension of prediction), it is also possible to adopt a purely-geometric approach, delineated by the *Morphometry* [8]. Indeed, this methodology is capable of giving insights also on the performance of a system, if the geometry of a system is related to some technical characteristics of interest (as it will be illustrated in the present case).

1.2 Aims of this study

The present study will firstly focus on the overall evolution and design of the farm tractor, tracing the genealogical tree that led to the current types thanks to the TRIZ and the Morphometry (section 2). This will also be an opportunity to ponder the technical reasons (and whether these reasons are still valid) that have led the tractor to take on the geometry that is commonly associated with the very idea of a tractor (i.e., the so-called “conventional architecture”; sect. 3), in a sort of consolidated and now permanent association between form and substance, between physics and metaphysics, between reality and Platonic hyperuranion. Secondly, this study aims also to examine the technical solutions, present both in actual tractors and in tractor architectures no longer on the market (sect. 4), and individuate which of them are worthy of being considered (or recovered) in possible future tractors capable to cope with the new challenges of hybridization and robotization, expressing different technical needs but presenting also new opportunities to the designers (sect. 5).

2 Origin and Development of Farm Tractors

The development of the first farm tractors is part of the development of all mechanical aids to human labour in agriculture (firstly: the farm implements), which has characterised human history since the development of agricultural practices and technological means, where the latter were used to implement the former with a higher and higher level of (energetic) efficiency. All advances concerning agricultural machinery (in terms of design, materials) could be referred to as *low-tech mechanisation*. The

development of the farm tractor as a means of generating the mechanical power needed primarily for traction (hence the name “*tractor*”) is much more recent and can be traced back to the development of the first engines during the Industrial Revolution, started in the second half of the XVIII century. As the tractor has a much higher complexity level than all the equipment developed previously (mainly implements thought to be pulled by animals, like: horses, oxen), the initial ambit of development is that of Mechanical Engineering, and in particular the Railway Engineering: the first farm tractor, i.e. a self-moving machine to be used off-railway for agricultural tasks, was steam-powered and can be dated back to 1868 (Fig. 1). The subsequent tractors, although fuelled differently (with: gasoline, kerosene, diesel oil) thanks to the adoption of an internal combustion engine, had still the same architecture, very similar to a locomotive (Fig. 2), and presented some distinctive traits that are still present in the most widespread-ever configuration of modern tractors, referred to as “*conventional tractors*” (more rigorously: “tractors with a conventional architecture”).

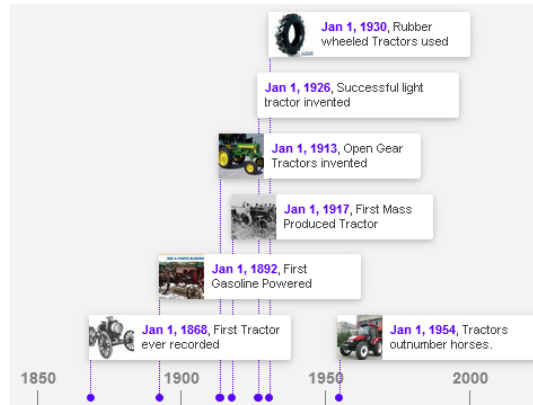


Fig. 1. Timeline of farm tractors milestones; the first tractor (1868) was steam-powered and it was used in the lumber industry [9].



Fig. 2. (left) 2WD gasoline-fuelled farm tractor “Aultman-Taylor 30-60” (1911); (right) 2WD kerosene-fuelled farm tractor “Case 20-40” (1919) [10].

However, considering the different types of farm tractors appeared since 1868 onwards, the characteristics of actual farm tractors and the TRIZ evolutionary trends, it is possible to hypothesize basically *two main parallel evolutionary lines* with a contact point represented by implement carriers, illustrated in the subsequent sections (see Fig. 3; the TRIZ evolutionary trends of reference are reported in the figure):

1. the **conventional tractors** powered by an endothermic engine, descending from steam locomotives (Fig. 2), which in turn descended from animal-towed carriages, originated at the beginning of the 20th century come down to us today in the two- or four-wheel drive configurations; these tractors are characterized by a rigid frame and two (or four) steering wheels. The cabin is usually positioned close to the rear axle, but there exist some variants with the cabin at the centre of the vehicle. The farm tractors belonging to this evolutionary line will be the object of the following sections (section 3, 4) of the present study.
2. the **articulated tractors**, descended from walking tractors, i.e. from single-axle implements with a rigid frame and with no orientable wheels (in this case steering is performed by varying the rotation of the driving wheels); over the years, another axle was added to the first to give the vehicle a road configuration and allow it to carry the driver, who was previously on his feet (Fig. 4). These tractors are characterized by two frames connected together through a central joint and four wheels with the same diameter: the turning is operated by angling the two halves of the vehicle. While conventional tractors can be found with essentially any power level, articulated tractors have historically occupied market niches (Fig. 5): highly-specialised tractors (for orchards or vineyards) for a use in hilly/mountainous terrains (very small but agile), and high-powered tractors, to be coupled with implements having a very wide working front (used above all on the vast farms that characterise the northern and southern America).

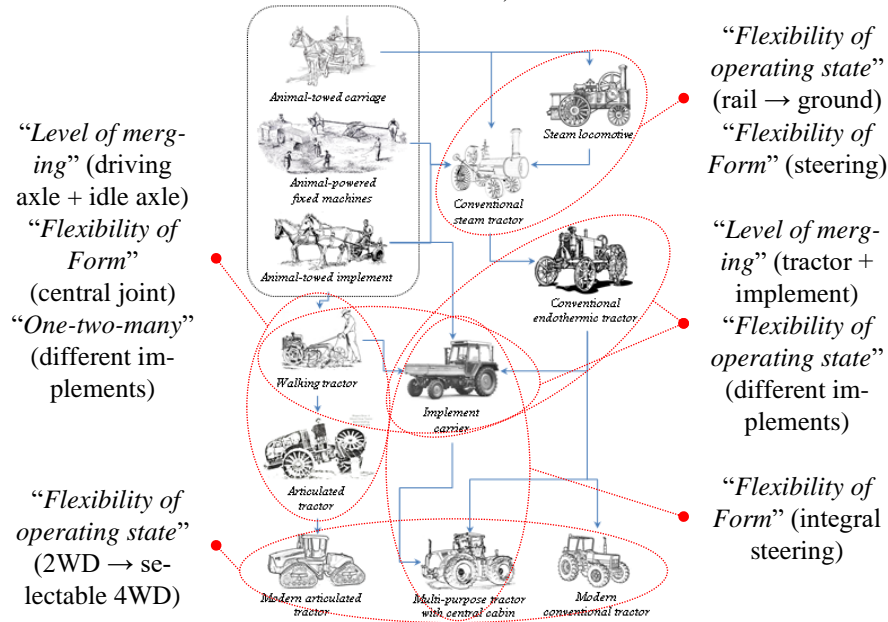


Fig. 3. Hypothesis of evolution of farm tractors from the animal-powered agricultural machinery; TRIZ evolutionary trends of reference are in red (some figures are taken from [11]).

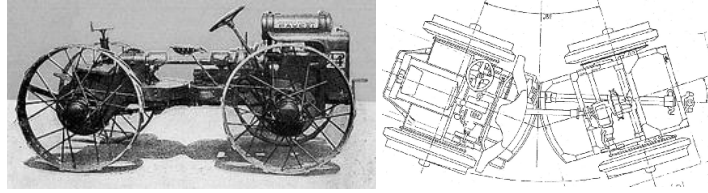


Fig. 4. (left) 4WD universal articulated tractor “Pavese-Tolotti P4” (1918) [12], (right) its conjugate-profile steering system with the two half-frames joined by a single tubular beam [13].



Fig. 5. (left) 4WD special-purpose articulated tractor “Antonio Carraro SN 5800 V” [14], (right) 4WD universal articulated tractor “Case IH Steiger 540” equipped with half-tracks instead of the pneumatic wheels [15].

Recently, electronic and electro-computerized systems have been introduced in agricultural machines, thus granting the mechanical systems, to which they have been interfaced, a more or less limited capacity for automatic adjustment. This further evolution, characteristic of *high-tech mechanisation*, although it has considerably improved the level of productivity of the “farm tractor” system, has in no way changed the general configuration of this system, which has been consolidated in the above-explained architectures for at least around 60 years.

Only with the introduction (at the moment only at the level of prototypes in experimental settings) of *robotic systems* (i.e. with autonomous driving abilities, manipulators, and the capacity to take decisions and interact with the surrounding environment), the architecture is being reconsidered (both in the frame and in the driving and steering members, e.g. as visible in Fig. 6) and some architectures of the past (in particular, the “implement carrier” architecture; Fig. 7) are being reconsidered, especially because of their handiness. Indeed, one of the greatest opportunities offered by an electric or serial-hybrid tractor is the interposition of electric wires in the powerline, which mechanically decouple the point of use of the power (the electric motors, one per wheel) from the rest of the system. The freedom to create the architecture is maximum in this case, and can be based on stability, weight distribution, compactness. In reality, however, many of the systems that are inspiring robotic engineers are often architecturally-different from the conventional farm tractors (section 3), not possessing the same universality of use (they require specific implements), and could instead be classified as self-propelled operating machines (section 4, final part), as they integrate also some tools used to perform the tasks for which they are designed. In any case, it is precisely as a consequence of these possible further future evolutions that *a consideration on the current configurations appears more than legitimate*, to

understand whether the time has come or not to introduce some significant variations also in non-robotic vehicles. The following question emerges among many others: has the evolutionary process that has led to the current conventional tractor, certainly incremental and probably not organic, really followed an improvement path? Is that current configuration the best possible one? Could it also be appropriate also in the future? Which other configurations were proposed hitherto? Are there some solutions of the past that could be still interesting nowadays?

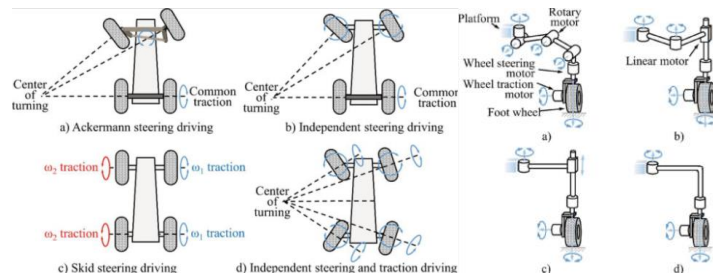


Fig. 6. (left) Different steering/driving systems for agricultural robots; (right) different solutions for wheel-legged structures (a :4-DOF articulated leg; b: 3-DOF SCARA leg; c: 2-DOF SCARA leg; d: 1-DOF leg) [16].

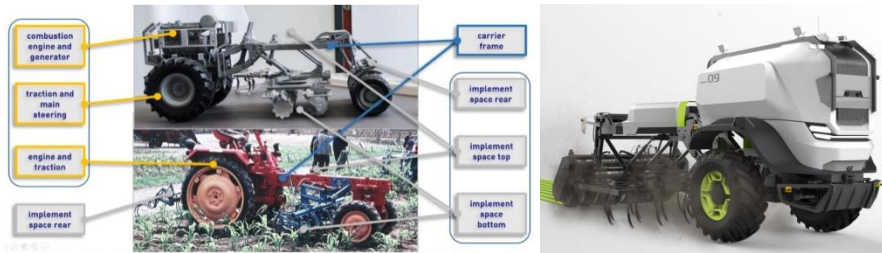


Fig. 7. (left) modular concept of the autonomous, self-propelled “Feldschwarm” unit and its design similarities to a implement carrier machine from 1960 [17]; (right) rendering of the “Feldschwarm” grassland module equipped with a cultivator implement [18].

Analysis of the Validity of the Main Technical Features Characterizing the Conventional Farm Tractors

Considering specifically then the *conventional farm tractors*, there are some questions that can be formulated by looking at their actual architecture/configuration (Fig. 8):

- Why does the architecture considered “conventional” present 4 wheels with the two rear (driving) wheels having a larger diameter than the front (directional) wheels, i.e. why do the front wheels have a smaller diameter than the rear wheels? Are the reasons still valid?
- Why, in the “conventional” architecture, the engine is positioned between the front axle and the geometrical centre of the tractor, while the cab is positioned between

the geometrical centre of the tractor and the rear axle? It is possible to hypothesize a different placement of these subsystems? In a possible repositioning are there some technical limitations responsible for the crystallization of the actual layout?

- Why does the chassis of the “conventional” architecture have just 4 wheels? Would it be possible to have other configurations with a different number of wheels?

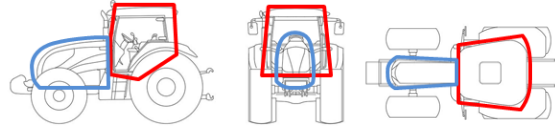


Fig. 8. Exemplification of a 4WD conventional farm tractor; in all the represented views, the blue frame individuates the engine, the red frame the cabin.

The *four-wheel architecture* can guarantee the maximum stability of the tractor with every inclination of the ground (in particular, the tractor lateral stability), due to the trapezoidal-shape support polygon with two sides almost parallel to the vehicle longitudinal axis. It is worthy stating that in some scenarios of hill agriculture, it is however possible to grant a sufficient lateral stability (however lower than a 4-wheel architecture) also with the 3-wheel architecture and an appropriate positioning of the vehicle centre of gravity, which in this case should be placed closer the axle that has the pair of wheels (i.e., closer to the wider part of the support polygon). Nevertheless, even considering this fact, the 4-wheel architecture is always preferable because it guarantees a greater universality of use than the 3-wheel architecture, due to the possibility of safely attaching any type of equipment also to the front of the tractor without compromising too much the lateral stability (Fig. 9). A sure advantage of the 3-wheels architecture with a single directional wheel at the vertex of the support polygon, is the possibility to have shorter turning radii thanks to the possibility for that wheel to rotate around the vertical axis passing through the centre of its footprint, without any constraint due to the chassis (as in a 4-wheel tr.). However, this fact cannot compensate the above-evidenced drawback on the stability.

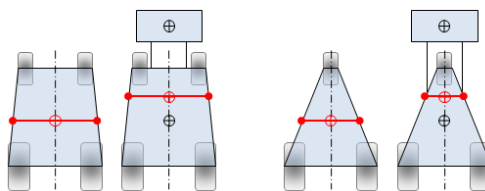


Fig. 9. Graphical exemplification of the superior residual lateral stability of four-wheel architecture over a three-wheel architecture (with the same dimensions and position of the centre of gravity) when connected to a front implement (e.g., a loader): the longer the red segment transversally cutting the support polygon, the higher the lateral stability [19–22].

The *rear driving wheels with a larger diameter* than the front ones have been introduced for two reasons, both related to the use of farm implements attached to the rear of the tractor (which are the majority) and, therefore, still valid:

1. If the implements are of the semi-mounted type, but, above all, of the mounted type (i.e., connected to the three-point hitch and kept entirely raised over the soil), the mass loaded on the rear axle is consequently increased; even considering the different grounds, in any case only a large-diameter wheel can guarantee a sufficiently-wide contact area to prevent excessive soil compaction (on this subject, it could be convenient to refer to the geometric calculation of the Nominal Ground Pressure [23, 24], a parameter useful for comparing different wheel diameters);
2. If the implements are towed, for safety reasons they must be connected at a lower height from the ground than the rear axle (Fig. 10), since this is the possible axis of rotation of the entire vehicle during a possible rearward overturning (it is a driving axle and the engine torque is applied there). A larger wheel diameter ensures a higher ground clearance for this axis of rotation and, thus, a greater possibility for a safe connection of even very different implements.



Fig. 10. (left) an example of safe hitching; (right) an example of unsafe hitching [25].

The front directional wheels with a smaller diameter than the rear wheels were introduced to have the widest possible steering angle for these wheels (i.e. the shortest turning radius), taking into account the dimensions of the tractor frame and the engine. Indeed, in the so-called conventional design, the frame is not articulated and the front wheels are always directional, whether the tractor has two or four-wheel drive. The restrictions on the steering angle (however $>50^\circ$) arise from the need to avoid collisions between the wheel tyre on the inside of the curve and the tractor structure (half-shaft and chassis; Fig. 11). Where possible, manufacturers have enhanced the “wasp-waist” design of the engine bonnet (Fig. 12), a feature that is characteristic of the conventional tractor design. Other configurations having four steering wheels, the rear wheels with a larger diameter than the front wheels and a non-articulated frame are quite rare, and proposed only as an optional for some conventional models; in such cases, the rear wheels have a limited steering angle (Fig. 13).

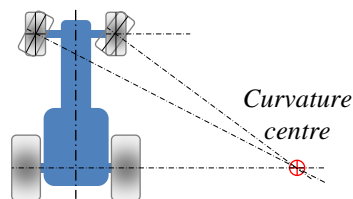


Fig. 11. During a rightward kinematically-correct steering manoeuvre, the most steered wheel is the one on the inside of the turn (i.e., in the front-right position in this picture).



Fig. 12. The slender design that characterizes this tractor, “Fendt 200 Vario”, allows it reaching in this case up to 52°-steering angle with the original-equipment wheels [26].



Fig. 13. The “SAME Frutteto CVT Activesteer” has a rear wheel steering angle of 18° [27].

The *positioning of the driver’s cab at the rear* is a direct consequence of the need for the driver to have full visibility on: (1) the three-point hitch (especially when approaching an implement to be connected), (2) the trailer (when manoeuvring rearward) and (3) the operative point(s) of some types of implement, especially those where there is a direct, immediate and adjustable interaction with the surrounding environment (e.g., a tillage implement interacts with the ground as it passes). In order to remedy the lack of visibility at the front, the cab is positioned at a height above the line of the engine bonnet (Fig. 14) and, at the same time, sufficient to have a better view of the ground in correspondence with the directional wheels.

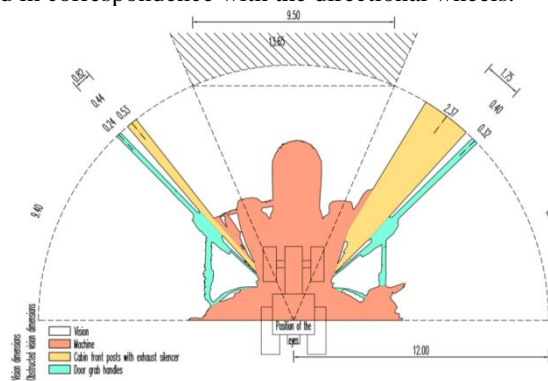


Fig. 14. Semi-circular front vision for the driver of a “Zetor Forterra 150 HD” farm tractor determined by using a Terrestrial Laser Scanner [28]. Thanks to the raised position of the cab, visibility to the front is excellent and reaches, in this case, about 90% of the represented 12-m radius front circumference.

3 Revision of Some Past Alternatives to the Conventional Tractor to Delineate the Future Tractor Architecture

The evolution of tractor has also shown some examples having a rigid frame but differing from above-discussed conventional architecture, albeit sometime limited to unique models. A gallery of these models has been reported hereinafter, together with a reasoned description of them (Fig. 15 and following pictures).

The first three examples show a *three-wheel configuration* (or something of comparable as in Fig. 17). The most unconventional of this group is for sure Fig. 15, presenting a unique driving wheel, shaped like a drum (or a roller). Although the roller has large contact surface area and, hence, may offer some advantages in terms of soil compaction and surface roughness levelling, it is so bulky that it forces the driver into a very backward position, which seriously compromises the visibility at the front. Critical issues also arise in the steering phase, due to the creeping that undoubtedly occurs in the outermost areas of the roller. This configuration therefore has no advantages over the conventional one and there is no reason to recover it even today. The other examples (Fig. 16, Fig. 17, Fig. 18) show instead a *single wheel at the front*, in one case even driving (Fig. 18). As already discussed in the previous section, this configuration has an unrivalled manoeuvrability that makes it still attractive even today, especially when combined with a lower centre of gravity, as in the machine designed for hazelnut cultivation shown in the Fig. 18, to compensate for the intrinsic lower stability than a four-wheel architecture.



Fig. 15. 1WD farm tractor “Gray 18-36” (1916); it uses a unique rear drum-drive system [29].



Fig. 16. 2WD farm tractor “OTO R3” (1950) (pictures taken from [30]); no differential is present on the rear wheels, the steering manoeuvres were performed acting at the same time on the steering wheel and on pedals controlling some clutches and the brakes.



Fig. 17. 2WD farm tractor “John Deere model B” (1934) and “model G” (1937)



Fig. 18. 3WD hydrostatic farm tractor “Fagma Trifrut” (2010) (left) as it is or (right) with a rear hoeing machine [31, 32].

In the second set of proposed models (Fig. 19 and following pictures), the first and most important thing to observe is that these examples turn out to be more than just some alternative configurations for the farm tractor, as they add other functionalities to let the vehicle be configured as an *implement carrier*. This is a universal machine that can be considered both as a tractor with also (limited) loading capacities for solids and liquids (by means of specific accessories to be placed on it, respectively: dumpers and tanks), and as a self-propelled operating machine, although not limited to a single crop-care operation and set of implements, to be connect ventrally at the centre of the chassis. It can rightfully be classified within the category of tractors because the basic functionalities of these are preserved: (1) the possibility of towing implements and trailers (although with some limits, due to the weight lighter than conventional tractors), (2) the possibility of connecting semi-mounted and mounted implements to the three-point hitch, (3) the possibility of operating implements via the PTO and the hydraulic couplers. The most modern examples of these vehicles (Fig. 22 and following) show, first of all, that a greater compactness level for the power-train, free from the transaxle configuration (so as to mount the cabin on the engine), is technically possible (especially for tractors with a single driving-axle), thus anticipating the possibilities of electric drives. In addition, the possibility of carrying implements directly on their chassis allows for a better weight distribution, which is useful both for limiting the soil compaction and for ensuring the overall safety of the vehicle (in terms of stability and directionality). The central position of the cab (Fig. 23, Fig. 24) is optimal for ensuring an optimal 360°-visibility, surely higher than conventional tractors. Moreover, some models have also a reversible cabin (Fig. 24) with the axis of rotation placed so as to bring the reversed cabin just over an axle and let the tractor use some implements normally designed for self-propelled mowers and forage harvesters, requesting a high power. This is why the few models of tractors with this

architecture in the market have usually a very high nominal power and important dimensions. However, the advantages listed are so many and so significant that it would be desirable to see the mid-cab configuration extended to machines with other level of power.

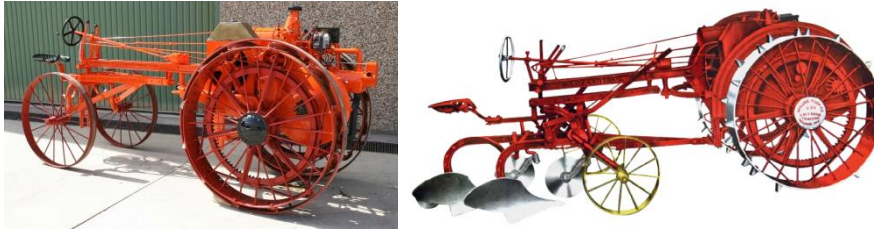


Fig. 19. 2WD articulated-frame implement carrier “*Moline Universal 10-12*” (1915-16) (left) as it is [33] or (right) equipped with a two-furrow plough [34].



Fig. 20. 2WD implement carrier “*Allis-Chalmers G*” (1948) (left) equipped with a cultivator [35] or (right) equipped with a mechanical seed drill [36].



Fig. 21. 2WD implement carrier “*FM Multi 28 L – 33 L*” (precise year unknown) with different accessories/implements: seed drill (top left), boom sprayer (top right), cabin (bottom left), ridger plough (bottom right).



Fig. 22. 32.9-kW 2WD implement carrier “Fendt F 345 GT” (1984) as it is (top left) or with a front loader and a rear rotary harrow (top right), a front seed drill implement (bottom left) or a dumper loading bay (bottom right) [37, 38].



Fig. 23. 4WD multi-purpose tractor with central cab “Fendt Xylon 320” (1994) as it is (top left) or with a plier (top right), a boom sprayer equipment (bottom left) or a sowing implement (bottom right) [39–42].



Fig. 24. 4WD 4-wheel-steering multi-purpose tractor with rotating central cab “Claas Xerion Trac VC” (2005) in the standard configuration (top left), with the cabin in the reverse position (top right), with a specific trailed (bottom left) or mounted (bottom right) manure spreader equipment [43].

To close this excursus, hereinafter there are other interesting examples (Fig. 25 and following pictures) in which, however, the machines no longer have some of the functions listed above, which characterise the farm tractors. In all these cases, indeed, the resulting machine is merely a *self-propelled (universal) operating machine* and, strictly speaking, should not be considered in this study apart from some specific technical solutions. These machines are, in a certain sense, the exasperation of the concept proposed above of a mix of a tractor and an operating machine/agricultural implement, where the ultra-specialisation has made them lose part of their universality.

For example, the first models of this set of machines (Fig. 25) are commonly indicated to as “gantry tractors” or “wide-span tractors” [44], have a scheme very different from the conventional one, which makes them particularly scenic. They were thought to limit the agricultural soil compaction by raising the machine working front as much as possible, and continue to be studied and developed also nowadays [45]. Also in this case, the classification of these machines within the category of “tractors” is incorrect, due to the lacking of the basic features of a farm tractor, previously explained. Gantry tractors, although having some remarkable features, are so impractical to manoeuvre to be not-interesting in delineating a possible future tractor. The high-frame (or adjustable-height frame) architecture with power transmission via a hydrostatic drive with four hydraulic motors (one per wheel; Fig. 27) allows carrying out operations even on growing crops. Apart from providing the maximum versatility of use, it is the most interesting of this group also because it can easily be upgraded with four electric motors in the future without altering the architecture. Finally, the last

example (Fig. 28) is characterised by the presence of two rear pivoting and idling wheels and, therefore, it presents the maximum mechanical simplification for the directionality system (in this case carried out directly by the drive wheels by controlling the rotation speed of each individual wheel). Although interesting, having the traction on all the wheels could be advisable in some field conditions, so this solution is not advisable in possible developments of the farm tractor.



Fig. 25. Universal operating machine “Gantry”; first 2WD prototype by Dowler (1970) equipped as fertilizer spreader (top left); first 2WD commercial version “Monotrail” (1983) as it is i.e., without any implement installed (top right); latest 4WD 12-m-width version (1990) as it is [46] (bottom).



Fig. 26. 2WD universal operating machine “AVCO New Idea Uni-System 700” (1980) as it is (top left), with a forage harvester equipment (top right), with a seed drill system (bottom left), with a boom sprayer equipment (bottom right).

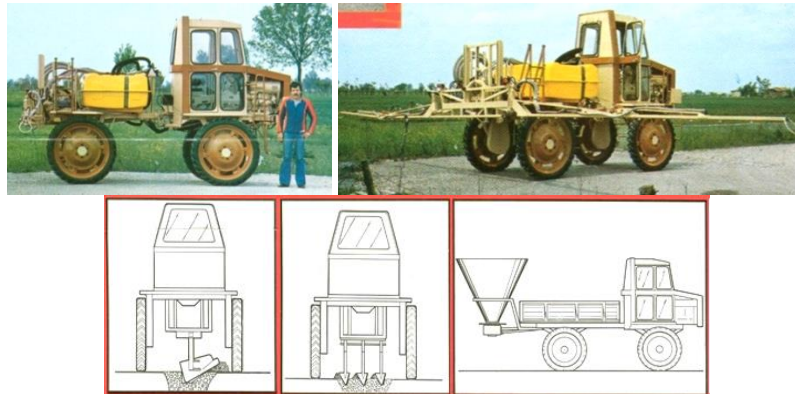


Fig. 27. 4WD universal operating machine “Lami Ibis 445” (about 1980) equipped with: a boom sprayer equipment (top left, top right), a plough (bottom left), a ridging plough (bottom centre), a manure spreader (bottom right).



Fig. 28. 2WD windrower with reversible driving commands and two pivoting wheels “MacDon M150” (2001) [47].

4 Conclusions

The TRIZ and the Geometrical Morphometry have allowed the identification of two main lines followed in the evolution of farm tractors, which have essentially given rise to two macro-categories, still present on the market today, namely: the *conventional tractors* and the *articulated tractors*. These categories have been complemented by other types of tractors derived from them, some of which are fairly recent, such as *central cab (conventional) tractors*, as well as by numerous attempts at other configurations, which have often remained unique. What has determined the (total or partial) success or failure of these different configurations has not been the more or less strong justification regarding the technical systems and solutions adopted or the architectural choices made, but, rather, the *universality of use* of the machine itself. This last characteristic is to be intended, above all, as the possibility for novel machines to use the agricultural implements already present on the market, i.e. without necessarily forcing a possible buyer to also renew all the agricultural implements at the same time as the tractors. According to this consideration, it was possible to observe the disappearance of many “implement carrier” tractors, some of them very interesting by a technical point of view, and, at the same time, also the survival of few examples of

central cab conventional tractors, interesting as well, beside the two above-delineated main groups. On the basis of the considerations that have been made, it is possible to say that most of the technical choices that are now consolidated in the conventional tractors are still justified for that configuration (e.g., the 4-wheel architecture, the front/rear driving wheels with a smaller/larger diameter, the driver's cab at the rear), but they can be partly surpassed by considering some features that characterize the illustrated alternative tractors and which deserve to be present also in future farm tractors (specifically: a limited loading capacity, ventrally-attachable implements, central cabin, adjustable-height frame, all wheel driving and steering). These features, suitably introduced and reconsidered with a particular attention to the standardisation of interfaces (to grant the universality of use), could determine the future success of a possible novel universal tractor configuration (therefore no longer relegated to a single market niche as central cab tractors are now, for example), also with a view to future electrification, hybridisation and robotisation of agricultural machinery. In particular, a novel architecture should be characterized at least by the following systems/features: *an adjustable-height rigid chassis with the possibility to attach implements also below it using a sort of foldable three-point hitch, the driver's cabin in a central position but displaceable at the front, four driving and steering wheels, a single motor per wheel, all wheels with a large diameter, a standard three-point hitch at the front and another one at the rear, a hook placed always below the wheels axles.*

References

1. Hull, D.L.: Science as a process: an evolutionary account of the social and conceptual development of science. The University of Chicago Press, Chicago and London (1988)
2. Dennett, D.C.: Darwin's Dangerous Idea. Simon & Schuster (1995)
3. Gautschi, D.A., Sabavala, D.J.: The world that changed the machines: A marketing perspective on the early evolution of automobiles and telephony. Technol. Soc. 17, 55–84 (1995). [https://doi.org/10.1016/0160-791X\(94\)00026-A](https://doi.org/10.1016/0160-791X(94)00026-A)
4. Li, J.S., Chen, L.H., Li, L.: Parametric Design of Tractor Configuration Using API Based on CATIA. Key Eng. Mater. 455, 411–416 (2010). <https://doi.org/10.4028/www.scientific.net/KEM.455.411>
5. Chandrasegaran, S.K., Ramani, K., Sriram, R.D., Horváth, I., Bernard, A., Harik, R.F., Gao, W.: The evolution, challenges, and future of knowledge representation in product design systems. Comput. Des. 45, 204–228 (2013). <https://doi.org/10.1016/j.cad.2012.08.006>
6. Guzzomi, A.L., Maraldi, M., Molari, P.G.: A historical review of the modulus concept and its relevance to mechanical engineering design today. Mech. Mach. Theory. 50, 1–14 (2012). <https://doi.org/10.1016/j.mechmachtheory.2011.11.016>
7. Altshuller, G.S.: Creativity as an exact science: the theory of the solution of inventive problems. Gordon and Breach Science Publishers Inc., Amsterdam, The Netherlands (1984)
8. James Rohlf, F., Marcus, L.F.: A revolution morphometrics. Trends Ecol. Evol. 8, 129–132 (1993). [https://doi.org/10.1016/0169-5347\(93\)90024-J](https://doi.org/10.1016/0169-5347(93)90024-J)

9. BBids26: Tractors Through History, <https://www.timetoast.com/timelines/tractors-through-history>
10. Ferris, G.: Rare Tractors 2014, <https://www.youtube.com/watch?v=5aN7uQaxGJk>
11. Cianni, R.: Storia della Trebbiatrice (History of the Threshing Machine), <https://trattoridepocapiacentini.it/stor1trb.html>
12. Wikipedia: Pavesi P4, https://it.wikipedia.org/wiki/Pavesi_P4
13. Regio Esercito: Galleria Fotografica Modellismo - Trattorice Pavesi P4 100 Mod. 30A - 1/35, <http://www.regioesercito.it/modellismo/mod3.htm>
14. Carraro, A.: SN 5800 V - T Major Series, <https://www.antonio carraro.it/it/catalogo/sn-v-major>
15. CNH Industrial America: Steiger 540, <https://www.caseih.com/northamerica/en-us/products/tractors/steiger-series/steiger-540>
16. Gonzalez-De-Santos, P., Fernández, R., Sepúlveda, D., Navas, E., Armada, M.: Unmanned Ground Vehicles for Smart Farms. In: Agronomy - Climate Change and Food Security. IntechOpen (2020)
17. Herlitzius, T., Fichtl, H., Grosa, A., Henke, M., Hengst, M.: Feldschwarm – Modular and Scalable Tillage Systems with Shared Autonomy. In: LAND.TECHNIK AgEng 2019. pp. 409–420. VDI Verlag (2019)
18. Dezeen staff: Ten technology-driven design projects by Technische Universität Dresden students - Feldschwarm Grassland Module by Felix Schmitt, <https://www.dezeen.com/2020/07/08/technische-universitat-dresden-vdf-school-shows/>
19. Vidoni, R., Bietresato, M., Gasparetto, A., Mazzetto, F.: Evaluation and stability comparison of different vehicle configurations for robotic agricultural operations on side-slopes. *Biosyst. Eng.* 129, 197–211 (2015). <https://doi.org/10.1016/j.biosystemseng.2014.10.003>
20. Bietresato, M., Mazzetto, F.: Stability Tests of Agricultural and Operating Machines by Means of an Installation Composed by a Rotating Platform (the “Turntable”) with Four Weighting Quadrants. *Appl. Sci.* 10, 3786 (2020). <https://doi.org/10.3390/app10113786>
21. Bietresato, M., Mazzetto, F.: Morphometry as a Key to Investigate the Stability to a Wind-Induced Rollover of Agricultural Equipment for Irrigation. *Int. J. Saf. Secur. Eng.* 10, 129–139 (2020). <https://doi.org/10.18280/ijssse.100117>
22. Bietresato, M., Carabin, G., Vidoni, R., Mazzetto, F., Gasparetto, A.: A parametric approach for evaluating the stability of agricultural tractors using implements during side-slope activities. *Contemp. Eng. Sci.* 8, 1289–1309 (2015). <https://doi.org/10.12988/ces.2015.56185>
23. Mellgren, P.G.: Terrain classification for Canadian forestry. Canadian Pulp and Paper Association, Montreal, Quebec, Canada (1980)
24. Partington, M., Ryans, M.: Understanding the nominal ground pressure of forestry equipment. *FPInnovations.* 12, 1–8 (2010)
25. AgSAFE: The FARSHA Guardian Bulletin. , Langley City, BC V1M 3Z4, Canada (2015)
26. AGCO: Fendt 200 Vario, <https://www.fendt.com/za/fendt-200-vario-highlights>
27. SDF group: SAME Frutteto CVT ActiveSteer, <https://www.same-tractors.com/it->

- it/passione/news-eventi-passion/3074-same-frutteto-cvt-activesteer#prettyPhoto
28. Zemánek, T., Cibulka, M., Pelikán, P., Skoupil, J.: The Use of Terrestrial Laser Scanning for Determining the Driver's Field of Vision. *Sensors*. 17, 2098 (2017). <https://doi.org/10.3390/s17092098>
 29. Blackboard Inc.: The Gray Tractor Built in Campbell Minnesota, <https://www.campbell.k12.mn.us/Page/537>
 30. Menatti, R.: OTO Melara Trattori agricoli - Il museo di Oto-Rino - OTO R3, http://trattori-oto.it/index.php?menu=100&id_articolo=6&id_prodotto=1&tipo_prodotto=1
 31. Facma: Our products, <https://www.facma.it/prodotti.asp?lang=eng>
 32. Facma: Technical Innovation EIMA 2010: TRIFRUT tractor, <https://www.facma.it/dettaglioNews.asp?lang=eng&IDNews=27>
 33. Museudeltractordepoca.com: MOLINE UNIVERSAL | 10-12, http://museudeltractordepoca.com/en/portfolio-items/moline-universal-10-12_en/
 34. Zampicinini, F.: I portattrezzi: instancabili tuttofare, <http://www.macchineagricoledomani.it/include/fileviewer.asp?ID=228>, (2010)
 35. Greensboro Auto Auction Inc: Legendary "G" Series Cultivator, <https://www.gaaclassicars.com/vehicles/27804/1948-allis-chalmers-model-g>
 36. TractorData.com: Allis Chalmers G Photos, <https://www.tractordata.com/farmtractors/000/0/0/6-allis-chalmers-g-photos.html>
 37. TractorFan Italia: Fendt F 345 GT Immagini, <https://www.tractorfan.it/pictures/type/31429/>
 38. Wikibooks – Die freie Bibliothek: Traktorenlexikon: Fendt F 345 GT, https://de.wikibooks.org/wiki/Traktorenlexikon:_Fendt_F_345_GT
 39. TrattoriWEB: Fendt Xylon. Rivoluzione incompiuta, <https://www.trattoriweb.com/fendt-xylon-rivoluzione-incompiuta/>
 40. Wikibooks – Die freie Bibliothek: Fendt Xylon in Winterthur, https://de.wikibooks.org/wiki/Traktorenlexikon:_Fendt#/media/Datei:Fendt_Xylon_in_Winterthur.jpg
 41. Maskus.it: Fendt 524 Xylon in vendita - Danimarca, <https://www.mascus.it/agricoltura/trattori/fendt-524-xylon/hobmaxfn.html>
 42. Tandtje: Landb. Vansteelant - Torhout - Fendt Xylon 524 - Fendt Favorit 824, <https://www.youtube.com/watch?v=H8nCMssI5ys>
 43. CLAAS KGaA mbH: XERION 5000-4200 - Il concetto TRAC, https://www.claas.it/prodotti/trattori/xerion5000-4200-hrc_2020/trac-varianti
 44. Bulgakov, V., Adamchuk, V., Kuvachov, V., Ivanovs, S.: Research of possibilities for efficient use of wide span tractor (vehicle) for controlled traffic farming. Presented at the May 24 (2017)
 45. Bulgakov, V., Adamchuk, V., Kuvachov, V., Arak, M., Olt, J.: Study Into Movement of Wide Span Tractors (Vehicles) Used in Controlled Traffic Farming. Presented at the (2017)
 46. CTF Europe: The history of gantry tractors, also known as wide span or wide track vehicles, <https://www.gantrytractor.org/history>
 47. MacDon: M1 Series Windrowers, <https://www.macdon.com/en/products/m1-series-windrowers/>