INNOVATION IN THE FARM TRACTOR WORLD – 1970-2010 Who Leads? Who Follows?
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Summary

This paper looks at significant innovations in the world's tractor industry over the past 30 years. The industry has changed out of all recognition in this period when organizational change has been at least as important, in shaping the future, as technological change. Here, Graham Edwards examines both kinds of change and attempts a little 'futurology'.

He begins by viewing the global industry, as a whole, and uses the 1970 paper by A.R. Reece (The Shape of the Farm Tractor) as a starting-point and refers to the Mercedes-Benz Unimog, the Agricultural Land Rover development (4x4 pick-up trucks), the MB Trac and Intrac as related but different concepts. He also traces some of the influences at Land Rover, Unimog, M.B. Trac and other 'different tractor types' in farming and attempts to place the Xylon, Xerion, Fastrac and Trantor tractors in the context of innovations within in the world's tractor industry. The relevance of newly-emerging "tractor-vehicles" is outlined in regard to current tractor production volumes, varying specifications and market sectors. Table 1 (attached) indicates the place of innovative vehicles in the various horse-power related conventional market sectors. The paper contrasts the revolutionary innovation of some designers and manufacturers with the, incremental innovation and frequently pedestrian innovativeness of others.

Having regard to the world's vast and growing manufacturing volumes of China and India and the recent phenomenal reduction of volumes in Former Soviet Union (FSU), the author attempts to assess the way some of the tractor makers are moving production into new factories outside of Europe and USA and into India, Brasil, Pakistan and Turkey. He attempts to examine the way innovation may influence the plans of important and emerging countries and companies and notes that R&D, design and marketing is currently centred on the headquarters of the main groups mainly in Italy, USA and Germany.

As part of his presentation the author uses his 30 years of tractor development and market research work in the field of farm tractors to explain the way the worldwide tractor industry has moved and may change in future. It was the ASAE session 2002 on Higher Transport Speeds in Chicago that was the first meeting (in the last 30 plus years) to try to deal with the subject of "travelling more quickly and more efficiently by farm tractor". Sadly, the conference session was not only poorly attended (indicating the unimportance attached to improved tractor productivity to the ASAE members of USA) but dealt largely with engineering minutiae, which is more relevant to the non-innovating tractor companies of John Deere, Agco and its satellites, Italian Fiat with names like Case and New Holland, Same-Deutz and the Argo satellites (Landini-Macormick, Valpadana).

The views expressed in the article are entirely his own and have been formulated as a result of working within the farm tractor industry since 1970.

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John Deere, and Agco (Massey Ferguson, Fendt, Valtra, Deutz Allis), are U.S.A.- controlled and managed whilst Argo (Landini, Macormick Valpadana), Same-Deutz, and Fiat (New Holland, Ford, Case, and Steyr) are Italian controlled and managed. All 5 are large multi-national businesses. Whilst Britain and Germany are conspicuous by their absence as owners of large multi-national producers of conventional tractors both countries have some exceptional and innovative companies, and some excellent tractor design engineers. The Trantor® tractor and JCB Ltd., firms in U.K. are both small (in agriculture) with significant innovative vehicle and tractor technology based on full vehicle-type suspensions.

In Germany, there are rather more small volume tractor makers but Claas having bought Renault tractors have joined the mainstream whilst Horsch and Holder-Uzel are two particular specialists who focus on particular segments of some key markets. The JCB Fastrac is focused largely to arable farms with widespread ploughing acreages and farm managers who want all their tractors to plough. The Trantor tractor is focused on farms with many tractors where farm managers seek all-round efficiency but recognise the horses for courses strategy of tractor use, and so use lighter and faster transport-first vehicles for haulage, spreading, spraying, and p.t.o. cultivation (soil-engaging), as well as for lower-draught work with ag-implements which improve the seed bed, because of higher speeds. The innovative German approach has been largely focused towards combining as many tasks as possible with one pass over and through the land whilst the English have adopted full-vehicle-like-suspension as the basis of innovative design.

The Conventions in tractors

The mainstream tractor makers have all begun their conventional ploughing-first tractors designs without considering suspension on their axles and with the absence of front wheel braking . They all make a wide range of more than 30 models, all of which are much of a much-ness but they do differ in horse power and weight and, of course, in colour!!! Whilst the mainstream is defined by wide range, convention and high volume so is the second tier but here simplicity and older designs of a smaller range were made in big volumes by Zetor, Ursus, Belarus, IMT and UTB Tractorul (Universal). They all used to make many more tractors than they do now. Their tractors were traditionally simple and low-cost and were subsidised by FSU (Former Soviet Union) policies. Their future is in doubt, for they are not finding the market economy easy to respond to and production and sales volumes are rapidly declining. The third group of tractor manufacturers are those who make lots of tractors to their own design e.g. Punjab Tractors (Swaraj) Ltd. (PTL) of India or to someone else's outdated designs e.g. Mahindra & Mahindra (M&M), and Tafe-Eicher and sell them largely in their own home markets. These producers make a small product range of primitive design at a price, which is less than 25% of that common in Europe. They have no safety cabs, no 4 WDrive, no synchro-mesh and they sell like hot cakes!!

Innovation Not Interesting

All of these 3 groups of tractor makers are characterised by their abysmal approach to innovation. Not only are they not pro-active, they only move when forced to by legislators, e.g. safety cabins and noise levels. Had regulators worked well with a pro-active tractor industry over the past 20 years adding front brakes (for safety) would have preceded safety cabs and a sensible approach to noise-level might have been possible. The legal necessity of low noise level cabs has encouraged the quadraphonic rock sounds of cassette players to reach a decibel figure much higher than the earlier engine and transmission noises! As it is, the cart was placed before the horse in Europe from 1971when ROPS cabins became compulsory. In 2002, the beginnings of legislation for adequate 4 wheel brakes and suspension on tractors weighing in excess of 5 Tons became a consideration and a political hot potato. The Health and Safety legislators were beginning to address the vast health problem for tractor drivers whose spinal deformities had long since gone unnoticed, but are rather similar to the asbestos workers of former years. Spinal deformities of tractor drivers have not yet received the kind of public attention that asbestosis has received, across a rapidly growing European Community (EC), now 27 countries!

Production of Tractors is moving.

Whilst tractor sales and farm machinery sales are in excess of 40 million U.S. dollars, the tractor production volume around the world is rapidly changing. 230,000 tractors were made in U.K. in 1963 and only 52,000 in 1991. The most striking comparison, however, is that of India where the production volume in 2006 was nearly 300,000 units, up from 13,000 units in 1967. By 2002, there was a dramatic reduction in tractors made in Eastern Europe where the massive Romanian, Polish and Minsk (Belarus) tractor factories produced only a fraction of installed capacity. India's strident growth has followed from the consumption of tractors at home, for almost all their production volume is sold at home whereas about 70% plus of U.K. production was usually exported.

In East Europe, there has been a loss of markets due to changes to the economic system, whereas in Western Europe tractor sales have fallen by about 50% because a smaller number of bigger tractors with a higher performance are now bought. In order to understand the farm tractor industry in China it is essential to include the rural transport vehicle sector within the framework (see Bernard Stokes, Financial Times UK Report).

These RTV's are of a 3 and 4 wheeler kind and there are 250 registered tractor and vehicle factories throughout China. 155 make 4 wheelers at a production volume of around 3 million per annum which suggests that transport is particularly important and passenger -carrying by tractor and RTV to be very relevant indeed to the rural economy. A more recent survey of China's tractor industry is to be found in an article by David Phillips of Off-Highway Research, in the IVT International magazine (UKIP) 2006.

Britain Leads in Innovation.
The farm tractor business has always had its leaders in technological development and innovation and Britain has always featured strongly, as one would have expected from a country producing 230,000 tractors per annum in the 1960's. The main innovation from U.K. in the seventies was, however, in small firms with 4 WDrive tractors where County Tractors and Roadless Traction led the world, enabling County to sell 75% of their output to exports. As model ranges changed and tractor sizes grew, the large multi-national tractor makers simply invaded the market segments of County and Roadless and destroyed their businesses.

More recently and perhaps more interestingly a small company Trantor Tractors of U.K. (Trantor International Ltd. or TIL), grew out of the Engineering and Management Schools of the University of Manchester and it has quietly started to change tractor design thinking after some 20 plus years of innovation! Their approach is different from all others as their inventions are original (Appendix 1). Trantor tractors not only created the world's first fully-suspended farm tractor they have changed the way in which tractors are perceived, by creating the world's first transport-first farm tractors. These tractors are called TRANTOR tractors, and contained within their designs is a special kind of rear axle, hitch and linkage suspension (see Appendices 1, 2 and 3)

French and German tractor innovation.
Renault of France (now Claas-Renault) were the first of the conventional tractor makers to pick up the original ideas of Trantor tractor when they invested over £2m in developing their suspended-cab concept. Renault placed their suspension on top of the rigid main frame or skid unit, which itself has no suspension except its tyres!! It works well on smooth roads. On rough tracks axle suspensions are required. Fendt of Germany, in the period before becoming an Agco company, placed front axle suspension on to their ploughing-first tractors to counteract the "pitching and tossing" which results from handling equipment and trailers. They simply followed the designs found useful many years before and made some technical improvements.

Fendt and Renault (Claas) have been content to retain their heavy, ploughing-first tractors whilst making these changes their first innovative steps in the direction of all-round, vehicle-type suspension. The Fendt company,, (then a German independent family company and German market leader) was not influenced by any global design perspective which considered suspension as necessary. When they developed their XYLON tractor they developed it for German farmers who
had become accustomed (because of the Mercedes Benz M.B. Trac and Deutz-INTRAC designs of earlier years) to working with combination operations. (Two or more implements operated together during one pass over and through the land). The XYLON was an interesting and useful new product and it showed that Fendt were able to embrace front axle suspension in their new designs rather than add it as an after-thought, like others! (Table 2 in Appendix 3) outlines the state of suspension system development for tractors in 2002). Had Fendt been more imaginative, more innovative and more research led they might have discovered the suggestion in the." R.L. Kushwaha and C. Linke, (1) paper that "Rear Axle suspension positively improves ploughing performance!! Fendt and its innovations now belong to Agco of USA and the 'Xylon' is now extinct?

Innovation Comes From Outside The Mainstream
As frequently happens, innovation often comes from outside, and so it was for tractor rear axle suspension. Mercedes Benz had been adjusting their 4x4 military trucks to accommodate ploughs, just as Land Rover (1947-1949) had done with Adrolic in Scotland. The National Institute of Agricultural Engineering (N.I.A.E.) stated in 1949, "that you can plough with a Land Rover" but soon gave up the idea!! Mercedes Benz, however, continued to promote and develop the front and rear axle suspended UNIMOG as a ploughing and farm transport vehicle. In 1971 they introduced the M.B. Trac (without rear suspension), which was made with some UNIMOG components. This tractor was unconventional but was quickly accepted by farmers in the 3 main tractor markets of Europe, (U.K., France and Germany). This MB Trac tractor had front suspension only. Influenced by Land Rover and knowledgeable about Unimogs was a young man called Stuart Taylor who had conducted some statistical research on large British farms for his Masters Degree (2). He acquired the notion that a new kind of vehicle was required on farms which combined the features of Land Rover, tractor and truck. Around the same time, A. Reece (3) at Newcastle University explained the potential that existed in tractor development, if newer automotive-engineering technology was adopted by the tractor industry.

Taylor designed a tractor that speedily, safely and comfortably pulled a sizeable farm trailer. Farm trailers in Britain and France usually have two or four rear wheels and a drawbar (so that part of the trailer weight falls on the tractor) and their loads are frequently 2 or 3 times the weight of tractors. During harvest time (when the combines get bigger and faster) more tractors are needed to keep the work flowing, before the rain comes!

Taylor (2) believed that speed was important for timeliness and his notion of pulling less farm trailers more quickly at harvest time was his goal. Whilst Taylor considered that transport efficiency was a primary goal for U.K. farmers A.G. Milroy (4) explained that the concept had much wider relevance and, along with W. (Bill) Butterworth (5) at Writtle Agricultural College and now Land Network UK Ltd., believed that the idea had world-wide significance.

Land Rover Thinking Triggers Innovative Trantor tractor.
Taylor was, however, considerably less inhibited in his own company (www.trantortractors.com) than Land Rover design engineers had been in theirs. Land Rover's designers were always part of a motor-car company and the Land Rover Special Products Division was always constrained by car group policies. These caused them to appear to be unable to develop a vehicle, which was similar to Land Rover but bigger and more useful to farmers as a work vehicle. (George Mackie (6) explains this in his book with K. & J. Slavin). The Land Rover thus became a passenger-carrying and "horse-in-trailer" haulage vehicle in farming. Land Rovers' inadequacy for farm work caused another bright design engineer to devise, develop, manufacture and sell the Agrover (7) (Agricultural Land Rover with engine-speed power-take-off, 3 point linkage and high clearance axles) (8) until Land Rover decided NOT to encourage production of this vehicle (1986) and eventually refused to supply the basic Land Rover for conversion.

Land Rovers loss was Trantor tractor's gain. Stephen Castellani - (Agrover's designer) joined the Trantor tractor company. Taylor and Castellani soon began to try to show Massey Ferguson Industrial (now Terex-Fermec) that suspension could help develop the poor ride and awesome vibration of tractor digger loaders when moving from one work site to another, without the help of a large and expensive low loader. The evangelists preaching suspension from Trantor tractor (www.trantortractors.com) simply designed and built a fully suspended 50mph (80kph) tractor-digger-loader in the vain hope that Fermec would consider that suspension could become the leading technological interest of its tractor and construction businesses. The bureaucratic Massey Ferguson were far too pre-occupied, however, by Victor Rice's edict to take 52,000 people out of its workforce and in consequence JCB Ltd., followed through much later and gained a significant US military order for its fully-suspended back-hoe loader, exactly what MFI-Fermec had asked of Taylor and Castellani.

New Entrants Demonstrate Innovativeness.
Caterpillar of USA did not have an agricultural division for years until the company developed the Rubber-Tracked Challenger (9) tractor, before selling the Challenger factory at DeKalb and the rubber-tracked tractor designs to Agco. Claas of Germany were not a conventional tractor maker (until buying Renault) but were a world-renowned combine and forage harvesting company, focused on selling to big farms. It is therefore unsurprising that they have moved into developing large, special-purpose tractors called Xerion and later bought Renault tractors. Whilst CAT have been moving away from agriculture, Claas are becoming a more powerful force in European farming and seem likely to be a worldwide force in future.

JCB Learn From Pioneering Innovators
JCB Ltd. is also not a manufacturer of conventional tractors but a business which depends largely upon the back hoe loader (formerly based upon the conventional Marshall-Leyland farm tractor) and they too did not have any substantial products for farmers when they sought a skid unit and engine for their new back hoe in 1964. It took JCB about 15 years to develop independence from the conventional tractor skid. JCB began to be a force in U.K. farming, however, not through tractors but when their Loadall telescopic handler was developed and introduced to the market. By 1984, it was obvious that JCB required a companion product (to the Loadall) for 400 Acre and above arable farmers. By coincidence, Stuart Taylor's development of the Trantor tractor had reached a point in 1984 where the Trantor tractor was becoming appreciated by a wider cross-section of farmers across U.K. The Trantor tractor company wanted to grow faster and make some money for they had used all of their funds in proving that their ideas and prototypes made sense. They had built about 150 Trantor tractors by then and sold them in U.K. and abroad. The company's 2 owners had spent 12 years developing Taylor's original ideas and in seeking to work in collaboration with JCB, they sought a co-operative arrangement, which would retain the interest of the two entrepreneurs. They set about explaining to Sir Anthony Bamford, Gilbert Jenkins (M.D.) and Mike Butler (project co-ordinator high speed tractor project) that transport-first tractors are likely to be significant to the future of farming. It is not known how, or if, JCB Ltd., would have utilised the 2 "suspension-pioneers" had they purchased Trantor tractors but it is known that Trantor were rather frank and open about their designs and patents and provided copies of their patents and designs to JCB Ltd!

Two different specifications of Trantor tractors were purchased by JCB (Wootton Farms). Some years later the Fastrac appeared with a rear axle suspension system rather similar to that on the Trantor tractors bought by JCB Ltd.

Improvements of late have caused the FASTRAC to be well-regarded as a ploughing-first tractor, but too heavy and unmanoeuvrable to be a transport-first tractor just as Land Rover was too light and improperly designed to do the work of a light tractor. The Fastrac is clearly a significant development in European farming and, as an innovative tractor, demonstrates to John Deere and the other "majors" what is possible when the ideas originated and pioneered by Taylor (2) and explained in the Kushwaha and Linke (1) paper are applied to the design of ploughing-first, conventional tractors.

(In Seville, Spain in October 2001, John Deere showed a prototype ploughing-first tractor with a form of rear axle suspension and in 2006 Fiat New Holland showed a similar prototype with suspension).

What Does The Future Look Like?
In such a milieu, the Indian tractor companies are simply not yet at the party. John Deere seems to plod from one success to another, The East European tractor makers have closed down more than 80% of tractor production in FSU and Romania. Now that Case and New Holland are one Fiat tractor company they are much more likely to invest in a rationalised product range than be innovative. John Deere continue to make healthy profits from focus, clarity and doing the simple things very well.

Quite when leaders of the world's big tractor manufacturers will look carefully at the real needs and uses of most of the world's tractor buyers is not known. One thing is sure, by 2006 they were all looking elsewhere and to Germany in particular for more complexity and more weight and more Horse Power – see graph of average HP sold in UK which reached in excess of 135 hp in 2007 from 80 hp in 1980.

Any rational view of the globalisation of the tractor industry must, one day, surely recognise the real needs of China, Africa, India, Turkey, Brazil, FSU and Mexico. Any assessment of rural and village community needs in these and other countries must certainly encompass passenger-carrying in and on farm tractors. This is a fact of life in vast regions of many countries where many sit very uncomfortably on tractors and travel very slowly indeed! Secondly, the amount of trailer-pulling done by farm tractors designed for ploughing and which are inefficient, slow, in-field and out and also uncomfortable for transport work is beginning to be recognised. Such awareness occurs now on sugar estates worldwide whereas it is also particularly significant on vegetable, sisal, palm-oil, fruit, cotton, and maize farming operations, for example.

It was Taylor (2) that led his team to appreciate the significance of changing tractor design to incorporate improved transport in British farming as Jenner (10) explained in relation to 3 significant Sussex farms. It was Lucas, N. (11) who first detailed how Taylor designed the Trantor tractor but Tony Milroy (12) (Silsoe Research Institute Overseas Department and Silsoe College) who brought to the Trantor tractor team an understanding of a transport-first tractor as a significant worldwide innovation. Milroy brought his unique skills into the Trantor tractor project as early as 1976, on his return from Yemen. His far-sightedness and ability to appreciate the fundamental needs of most tractor users in most countries was complemented by his illustrations of the way in which the Trantor tractor management team should develop Taylor's concept into a worldwide product and model range.

The management of Trantor tractors focused its main attention however towards staying in business in the difficult business period of 1985-1993 but, eventually Steve Castellani was able to develop a product range to suit current worldwide objectives and to achieve his goal by manufacturing various prototypes in India and creating an Indian supply-chain to keep costs down.

Price and Cost are Factors.

As far as the technology of ploughing-first tractors is concerned, JCB's Fastrac has a world lead in productivity and customer satisfaction (the driver's back being properly insulated from the normal jarring of conventional ploughing-first tractors) in those countries where £60,000 is a sensible price for farmers to pay for a tractor. Their future model range is likely to move up the H.P. brackets now that it is clear that John Deere's fully-suspended prototype has its entry point in the region of 280 H.P.!!

In countries where £10,000 to £25,000 is the price range considered sensible, the farmers Jeep or Land Rover farm transport work vehicle represents the only alternative possibility likely to meet user needs as Ketley (13) outlines in his analysis of the history of the Trantor tractor project. Taylor's Trantor tractor may yet satisfy Land Rover's original design brief (a farmers work vehicle) but also become the rural transport and work vehicle so badly needed in large countries like China, Mexico, Ukraine, Turkey and India with their vast agricultural acreage and many village communities. Of course the success and the volume depend on the cost, the price and the specification. In EC, USA, Canada, Australia and South Africa, the 2 and 4 WDrive Trantor tractors are clearly best described as general-purpose tractors and ploughing tractors seem likely to become special-purpose, heavy-cultivation tractors.

Health and Safety Considerations for tractor drivers.
It is well known that occupational health issues are progressively coming to the fore to affect the designs of tractors and other non-suspended products used continuously by hard working operators. The enforced presence of a ROPS cab (1971) on farm tractors was the technical change that has most affected designs in the post-war period. ROPS cabins protect the driver should the tractor overturn but they did nothing for the driver's back and spine and do not encompass an efficient braking system, akin to trucks!

Ride, Vibration and Operator Considerations
It has now become clear (2002) that the conditions of the backs and spines of tractor drivers will be important in future due to the various European Health and Safety inspectors who are sensibly concerning themselves with reducing the crippling affects of continuous driving of farm tractors which do not have an all-round, vehicle-type suspension system.

There are plenty of confusions and vested interests in the studies that emerged since Milroy (4) (1978) at Silsoe College conducted his work with Stayner. R. (14) at N.I.A.E. (Silsoe Research Institute) and showed, for the first time anywhere in the world that a tractor with axle suspension (called wheel suspension in some reports) could perform effectively towing trailers and transporting agricultural implements at a speed far in excess of that even considered, by the upper levels of the speed measurement systems (ridemeters) used at Silsoe in 1978. These ridemeters had been created to measure the ride and vibration of slow, up to 32 kph ploughing-first tractors produced by the mainstream tractor industry, which had not even contemplated higher road and field speeds for tractors, trailers and farm implements!

Silsoe's rigid-minded tractor researchers were interested more in evaluating the effects of suspended seats, suspended cabs and their various combinations, on existing conventional tractors and gave precious little consideration as to what kind of suspension should be encouraged. Closing down of this U.K. government-supposed tractor facility was sure to follow as evaluation studies demonstrated the lack of inter-disciplinary research done and the lack of fundamentalism shown by most leading staff which had become far too bureaucratic. Milroy, working at the nearby Silsoe College concentrated on demonstrating where and how conventional tractors were deficient and how the revolutionary, fully-suspended Trantor tractor (of 1978 design) could be improved. His hypothesis was simply that tractors had awesome ride and vibration levels when trailer-pulling, working with fertiliser spreaders, operating with mowers, and drills, and in far more real farm work tasks than ploughing! The new concept of transport-first tractors was principally designed for higher-efficiency whilst performing these very same tasks and he was astonished to find a fundamental lack of understanding at what was then U.K's National Institute of Agricultural Engineering (N.I.A.E). Whilst Milroy's views were to show the vast potential for developing faster and more comfortable and safe (to the driver) tractors for trailer-pulling and over-the-field-work, most of the N.I.A.E. tractor specialists at that time adopted the well known and most negative attribute, reflected in the "Not invented Here" syndrome alongside the business strategy of "working only with wealthy tractor firms". The paymaster of the piper called the tune in those days whilst government funds were too-frequently used for kite-flying!

Work on Ride and Vibration has, of course continued at Leeds University (D. Crolla 1990) (9) and at the RMS Vibration Test Laboratory (R. Stayner) (14) in Ludlow. Munich University has been helpful to Agco-Fendt (EVO) and John Deere but their influence has not always been a positive one, due to some narrow-minded views, (as far as concepts are concerned) of one or two prominent professors with an interest in tractors!

The implications of suspension on tractors are bound to be central to the work of future product development.

To date, there is a marked separation between various schools of thought:-

1. "We can build heavy (8 ton) tractors with massive load platforms and good ABS brakes which can travel at 65 KPH providing they have seat suspension and front axle suspension. They are expensive but can be used at about 200 H.P. for many hours per year".

2. "We can build high speed (80 KPH) tractors of about 7 tons weight with full all-round suspension which are good at ploughing and good at heavy trailer-pulling at 65 KPH and we provide various models with some considerable platform space. They are expensive and around £60,000 but can be used with all kinds of heavy ag-equipment".

3. "We think that most tractors from 70 H.P. should have suspension to assist with trailer pulling and over the field, lower draught work. We think the ride and vibration of a ploughing-first tractor is good enough for the few weeks per year that ploughing is undertaken. We think that more transport-first tractors should exist and there is more work for them, over the year, than ploughing-first tractors. We think that £10,000 to £30,000 should be the target price range in the 70 H.P. to 120 H.P. X 4WDrive market sectors. We think that light weight is vital to efficient farming and also low fuel consumption. (60% plus of the total tractor cost per year may be in fuel, as fuel costs continue to rise!)

In assessing the above 3 different philosophies, it is clear that there is no right answer. Each concept is different and undoubtedly has its place. An important question is, "which concept" will register the most worldwide sales by 2010? And which by 2020? Currently, over 99% of the world's tractors have no suspension at all, except perhaps for the 20% of tractors that have suspended seats. There are nearly no suspended seats in China, India and Turkey and yet those countries have more trailer-pulling and more passenger-carrying by tractor than in most other countries of the world (14). The question for the future is not therefore, whether or what suspension will be introduced but when? Seat, front-axle, cabin, trailer and implement suspension will become the norm on new ploughing-first tractors in future. It is likely that all-round vehicle suspension will be present on most new tractors by 2020 (15).

Changes in the Tractor Industry

30 years after A. Reece (3) (1970) outlined the way in which tractors would change; the industry itself has changed (more than the tractors) out of all recognition. Whilst Eastern European tractor factories may continue to make tractors in future they will be almost certainly controlled as part of a few multi-national tractor firms. China, too, may go in a similar direction largely because the multi-nationals will restrict the flow of technology, funds and the access to distributorships to those that are not controlled by them. Access to the vast East and Central Europe and China markets is largely controlled by the aid funds to these countries. It seems likely that 5 to 10 years will pass before Ukrainian, Chinese, Polish and Romanian farmers have sufficient self-generated funds to buy even a smallish tractor at say 30,000 US dollars, let alone a massive, modern, 8 Ton tractor at 100,000 dollars or more. It is, however, unlikely that the vast acreages with minimum tractorisation will be left fallow and therefore some international development initiatives will surely be made. Since the recipients of aid and world support programmes eventually have some say about what form the aid is to take, it must be expected that funds will be used to create jobs on farms and in tractor and implement factories. Assembly and manufacturing are likely, therefore, to feature as parts of the aid programme of emerging nations.

It is, not only money that will be required because the technology level and the manpower level in existing Chinese and FSU (Former Soviet Union) countries is unlikely to be acceptable to the aid recipients or providers, as evidenced by Chinese experience with car-producers! It is for this reason that the idea of a "tractor technology bank" has been created in U.K. It is the author's contention that not only could tractor technology banks be useful but they could be sited at, and developed by agricultural engineering colleges having a masters degree and research interest. Britain certainly needs to conserve and develop its tractor technology for this is a prime technical asset of UK plc, after so many post war years of 80% plus exports of UK -made tractors.

The largest tractor market (outside FSU and China) is India and their tractor industry is very different to those already mentioned. Tractor technology is at a lower level than even that of FSU. The Indian domestic market is very buoyant indeed. Manufacturing efficiency is good and India's excellent machinery is in stark contrast to their poor, old-fashioned tractor designs and very poor tractor finish. The Chinese factories have a much wider range of obsolescence but their inadequacy in the world tractor market is in design and in manufacturing efficiency. The latter will, of course be more quickly and more easily overcome.

India has a lead over China and FSU at present because Fiat, Same-Deutz and John Deere have entered the market whilst Valtra have joined with Eicher and Tafe. The John Deere product is not designed specifically for India and the Fiat-owned, New Holland factory is something to admire. These 2 tractor leaders have invested over 50 million dollars each in their Indian plants but their competitors (TAFE -Eicher, HMT, Escorts, M & M and PTL Sonalika) currently hold over 80% of the market share, with M & M (the market leader) with about 100,000 units made and sold in India per annum. There is no significant and profitable export market for the Indian tractors due to their primitive specification. Indian tractor makers are however now looking to export their tractors but they can only move in to exports slowly and all the Indian-owned producers currently lack the tractor technology essential for market entry in to the most profitable tractor markets. India's tractor-makers are, constrained by the past strength of their home market. Farmers in India buy the lowest cost and lowest specification of tractors and do so in ever-increasing volumes. Indian tractor makers have not needed to conduct analytical export market research. The effect of this is that the excellent profits already made have not been invested in R&D' and products of an export-directed kind are not yet available.

M & M – PTL make and sell about 100,000 tractors per year.

They are probably the third or fourth largest tractor maker in the world, Tafe-Eicher are close behind making about 60,000 per annum. Whilst Fiat, Deere and Same have entered India to try to take some of the market away from "India's big six", the big six themselves have to try to retain their own market share, and export tractors into export markets controlled by the 3 Indian-insurgents, plus Agco (M.F.Valtra and Fendt), the 3rd largest western tractor manufacturer.

Whilst FSU and China require funds and technology to be successful in future, the Indian tractor firms (except government-owned HMT) already have the funds and require only to find the "technology". Whilst funds for investment are available and well-used by M & M for distribution and marketing, by PTL for manufacturing, by TAFE for in-house component manufacturing, by Eicher for developing a supply chain, none of these companies have invested properly in obtaining tractor knowledge, tractor experience, tractor design, tractor development, tractor-testing, tractor safety and tractor efficiency. At senior levels of technical management these matters are conspicuous by their absence in all of India's tractor firms. As 2009 dawns, the Indian tractor makers are expecting to enter a worldwide market and all of them need advanced higher technology.

Innovation Future.

Table 1. outlines the seven H.P. sectors mentioned but also outlines the way in which tractor innovation has arrived. Additionally, it shows the particular innovations and the sectors of the market (by H.P.) of main relevance to each. When TIL introduced their fully-suspended Trantor, transport-first tractor in 1973 they did so at 50 H.P. and expected trailers of about 4-6 TON to be pulled at around 40 miles per hour on the flat, open roads. (17) When John Deere introduced all-round suspension on to their ploughing-first tractor (October 2001) 29 years later they did so at 280 H.P. Whilst TIL's directors have asked themselves many times, "when will the main tractor industry follow our technological lead?" they now know that the real question is not whether all-round suspension will arrive on farm tractors but when, how and on which of the seven market sectors of Table 1.

Conclusions

The main tractor companies have been pre-occupied with themselves, their mergers and amalgamations, their incremental and often minor design changes, their distribution channels, their movement of manufacturing from one country to another so much so that management at director-level is largely a political matter and rarely ventures into R&D, new product development and actual customer needs. After all, the distributor is supposed to report back to the tractor board what the customer thinks. Centre-Periphery systems rarely get the right message from centre to periphery and periphery to centre (BBC Reith lectures, Donald Schon 1967). In such environments change does not flourish with adventure and farsightedness but is dull and unimaginative, so that good professional and knowledgeable managers lose their jobs and incompetents frequently prevail. Looking from the outside, the big tractor firms, possibly with the exception of Deere, have been suffering badly from organisational chaos. The only explanation for the industry's poor record of knowing about or acknowledging innovation is similar to the way Hollywood failed to appreciate T.V. and, after bankruptcy, to become largely owned by T.V. and media companies. In short, the future is likely to be very different to the past. The tractor industry will change significantly. Some of the important matters expected to influence these changes and some important technical changes have been outlined in this paper.

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Appendix 1. – Full Suspension on Farm Tractors – the origin of the invention and the research study behind it.

Stuart Taylor began his study, 'The Tractor Requirements of a Sample of Large Farms in England and Wales' in 1971. He completed and published his report in May 1972, and registered his first patent in the same year. He designed and built his first prototype TRANTOR Tractor in 1973. Whilst his first patent (1,370,363) focused upon the requirement (for heavy trailer pulling) of having both a sprung (suspended) pick-up hitch (hook) and a self-levelling one too, it was the second patent which covered the principle of, "Locating the axle so that the effect of the overhang of the load on the axle (from linkage and hook) could be tailored to provide the desired effect on the vehicle suspension and ride level of the chassis - body unit, without the need to resort to active ride level systems on the vehicle". Whilst the first patent clearly gave Taylor's early TRANTOR tractor designs superior and much higher speeds for towing farm trailers (and most linkage-mounted implements of the 70's!) it was JCB's publicity for their HMV (the Fastrac) that highlighted the significance of Taylor's axle-location patents when Fastrac was launched in the 1990's.

JCB Ltd. have yet to publicly recognise Taylor's original work as a contribution so significant to their Fastrac-tractor development, despite buying two early Trantor tractors and JCB staff interviewing, studying and working with some of Taylor's pioneering and leading edge customers! It was, however, when JCB Landpower Ltd. stated that the Fastrac is the first "genuine" high speed tractor that they began to upset the apple-cart by pretending JCB had not worked with Taylor's team and, by implication, not studied his designs and patents when, in fact, the Fastrac designers carefully found a way <u>not to infringe</u> Taylor's patents, yet were able to follow his inventive lead. Furthermore, in response to questions of "where did the axle location principle come from?", the glib JCB answer, "from the Vauxhall Viva Car" is to fail to recognise that this torque (wheel drive torque around the axle, not load imposed on linkage and hook) is only a part of the torque imposed on the axles of the Trantor tractor and Fastrac. JCB Ltd., should, by now, be a big enough company, to give credit where it is due and acknowledge their debt to Taylor and his original British designs!

The world's first fully-suspended farm tractor was primarily focused upon the pick-up hitch (hook) of farm tractors, when hauling large farm trailers. (Imposing a heavy load on the tractor's hitch point) and also when carrying ag-implements (imposing a heavy load on the 3 point linkage) from field to field. The invention was patented so that the trailer load and the implement load were suspended (sprung) as the tractor and its trailer or implement moved around rough roads and farm tracks. Having invented the self-levelling, fully-suspended pick-up-hitch and associated suspended linkage, the patented axle system required to be placed on a tractor or on a vehicle.

The characteristics required by the rear axle, pick-up hitch and patent were not present on any tractor and tractors could not easily be developed to contain the new concept. The Land Rover and other 4x4 vehicles also could not easily contain the invention because of the strength and configuration of their chassis, the absence of a central driving position (important to working with trailers and implements), the shape and structure of their cabs, the wheel size and the strength of the transmission system. A completely new kind of vehicle cum tractor was thus essential. Taylor realised that his concept and the "new vehicle type" required would enable slow (30 mph) farm tractors to operate at higher speeds (50 mph) if the invention was placed on a vehicle chassis which itself was designed to travel at higher speeds.

Taylor formed his company to hold the patents and he personally built his prototype 55 H.P. x 2 WDrive Trantor (TRANsport tracTOR) which was then tested on farms around Manchester (UK). This proved that fully-loaded, 6 Ton trailers could be hauled safely by Trantor tractors and stopped safely (because of the more efficient, truck-type braking system of Trantor tractors) from 50 plus miles per hour. The Trantor tractor was comfortably able to carry 2 and 3 furrow mouldboard ploughs on its linkage, in the raised position, at similar speeds and more importantly over rough farm tracks without causing the bounce problem common to conventional ploughing tractors using rigid (unsuspended) skid-based products.

Appendix 2. - Developing the Invention.

Stuart Taylor and his associates entered small volume production of Series I Trantor tractors in 1978. Customers were found in Water Boards and County Councils due to the large amount of road work conducted by the tractors they had bought. Some farmers also bought Trantor tractors. To make Trantor tractors more acceptable to farmers and following some of the suggestions of early customers, Taylor created the Series 2 Trantor tractors, which could operate with heavier trailers and larger implements. Whilst Trantor tractors first patent focused upon the self-levelling pick-up hitch the second one focused upon the rear axle location in and to the chassis. (The weight on the hitch and linkage, from trailer and implement, causes the axle to try to twist. Trantor's second patent sets out to create a location system, which is designed to counteract that twist). This patent relates to the way in which the axle is located and moves in the chassis under linkage and hitch loads. The TRANTOR tractors were all built using this principle and much later (1991), the JCB Fastrac adopted a very similar design. (In 1984, discussions were held between Trantor tractors and JCB Ltd., and visits were made to some of TRANTOR tractor's pioneer customers by JCB's managers. JCB Farms, bought a Series 2, 4 WDrive x 96 H.P. Trantor tractor and a 6 Cylinder 2 WDrive x 128 H.P. Trantor tractor. Trantor loaned JCB Ltd., copies of their patents during the period because the Trantor team hoped that JCB Ltd., would help them develop their invention and the transport tractor concept).

<u>JCB's Fastrac Concept.</u>

JCB had gained from studying Trantor tractor's patents, and learnt something from Trantor's early customers but also from customers of the UNIMOG, and the MB Trac. JCB began by making a series of major decisions that would shape their development programme for over 10 years. Firstly they were persuaded that their new tractor would be fully suspended like the Trantor but would be a ploughing-first tractor (with suspension) rather than a transport-first tractor with suspension. JCB Ltd., also did not ever perceive that their new tractor would be a general-purpose tractor and thus the Fastrac became a heavy suspended ploughing-first tractor and in consequence the two principal objectives of Taylor's team were ignored.

It was some years before the Fastrac was to be understood by JCB Ltd., as being primarily designed for heavy cultivation, rather too big for most ordinary farms, very much too heavy for most transport jobs particularly farm haulage, spreading and spraying and certainly far too expensive (at cost) for most farmers in most countries!!

What JCB Ltd did and did successfully was to use Taylor's original ideas and create a fully-suspended ploughing-first tractor before John Deere, Fiat and Agco. It's design and its cost consequences were to make the Fastrac virtually unsaleable in most of the growing and developing markets overseas!

Appendix 3. – **British farm tractor technology leads the world**

The Trantor tractor was the world's first fully suspended farm tractor when first driven in 1973. It remained the only fully suspended farm tractor until 1992. The Trantor tractor is the world's only transport-first tractor because all other tractor firms consider ploughing to be the main task whereas the most time-consuming task of tractors is, in reality, transport. The Trantor tractor is British designed and has been continuously developed by over 400 customers in Britain and in 15 overseas countries. The idea of a command and support farm vehicle, more useful for farm work than a Land Rover, was a part of the thinking in the TRANTOR tractor development team. As time moved on, the development engineers found that potential sales into the really big markets including Asia, Africa, Australia, Middle East and USA accentuated the importance of transport and particularly so in dryland farming and where village-based systems of agriculture exist.

The following table shows the relevant aspects of innovation introduced by the world's leading tractor firms at 2002.

Table 2.	FORD CASE FIAT	MASSEY FERGUSON	FENDT	DEUTZ SAME	JOHN DEERE	MB TRAC	JCB FASTRAC	UNI-MOG	TRANTOR Tractors
FRONT AXLE SUSPENSION ON A FARM TRACTOR	NONE	NONE	SOME MODELS	SOME MODELS	SOME MODELS	ALL MODELS	ALL MODELS	ALL MODELS	ALL tractors from 1973
REAR AXLE SUSPENSION ON A FARM TRACTOR	NONE	NONE	NONE	NONE	NONE	NONE	ALL MODELS	ALL MODELS	ALL tractors from 1973
TRUCK STANDARD BRAKES (ALL TRACTOR WHEELS)	NONE	NONE	NONE	NONE	NONE	NONE	SOME MODELS	ALL MODELS	ALL tractors from 1973
SUSPENSION ON THE LINKAGE	NONE	NONE	SOME MODELS	NONE	NONE	NONE	NONE	NONE	All tractors from 1973
SUSPENSION ON THE PICK-UP HITCH	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	All tractors from 1973
3 Seats in the Cab	NO	NO	NO	NO	NO	NO	NO	ALL MODELS	All tractors from 1973
Power Steering Truck Standard	NO	NO	NO	NO	NO	SOME MODELS	SOME MODELS	ALL MODELS	All tractors from 1973

Appendix 4. - A Technology package.

Vehicle and tractor technology is normally owned by large multi-national companies. Tractor firms, such as Massey Ferguson (MF), Ford, Case, International-H, Deere and Fiat, have developed their own tractor technology and businesses over more than 75 years and have exploited their technology by way of manufacture at home with sales at home and in export markets. Some emerging countries have encouraged local tractor assembly and indigenous tractor manufacturing and some, like Turkey, Iran, Pakistan and India have large assembly plants with a substantial amount of local content, developed over a considerable number of years.

Firms like Land Rover have some overseas assembly, in Turkey and South Africa, for example, but the local content tends to vary from country to country. In the tractor world, Fiat, Ford and Massey Ferguson have been the most successful at providing local tractor assembly facilities to countries such as, Romania, Argentina, Brazil, Pakistan, Iran and Poland.

In all cases, the technology provider has licensed a lower level of technology to its associates and partners, than that which it has created for itself and usually uses at home. The provider thus controls its licensee through the rate of technology absorption but also by purchasing components from the licensee, which it then sells on as part of its own tractors or as components to other partners/licensees. Such procedures have been the foundation of the aims of Ford, Fiat, M.F., and others, to become global, multi-national companies.

In the new millennium, however, world trade was changing with young companies able to consider global strategies, once the sole province of a few, large, powerful, enterprises.

Additionally, the rapid rise of Asia as a major international manufacturing region, the breaking down of the barriers between Eastern Europe and China and the West has presented enormous opportunities for those with modern technology and the marketing skills to conduct the research, locate opportunities and market the technology.

British Innovation - from a small firm!

Whilst it is usual for the smaller firms of the tractor industry to be more innovative such as Fendt (IVT), Renault (with cab suspension) and Valmet (improved weight distribution) it is also usual for "revolutionary inventiveness" to come from outside the mainstream of most mature industries. The idea that a vehicle could be a Land Rover and farm tractor combined has some clear innovative appeal.

Working with Lonrho in Africa (1974-1982) – enabled the Trantor tractor team to understand the importance, to many African countries, of having their own motor vehicle industries. Since many African countries bought lots of tractors and plenty of Land Rovers, it was clear that a Land Rover cum tractor, which, with farm trailer would be a substantial truck, was a product with excellent sales potential. Lonrho were frequently asked to help initiate fledgling industries and motor vehicles were no exception. Lonrho therefore encouraged the TRANTOR Tractor design team, to develop a complete turnkey factory in which to make these vehicles.

After establishing the TRANTOR tractor with 400+ customers in Britain, Trantor developed its package of automotive and tractor technology and did so by designing its new range of modular tractors, in 2 WDrive and 4 WDrive, from 70 h.p. upwards using well proven, high quality, low cost automotive components.

Efforts to make use of this technology and the procedures necessary for technology-transfer have caused the UK owners of the Trantor International Ltd., (TIL) technology-package to create co-operative working R&D plus educational procedures with UK-based universities and UK-technology institutions. This is TIL's approach to ensuring that Britain retains its lead in automotive and Ag-engineering technology and management systems (for farmers work flow) and uses the British education and training institutions to support the transfer of technology.

Table 1.

Horse Power in the World Tractor Market	20-30HP	31-40HP	41-65HP	66-90HP	91-130HP	131-160 HP	161 Plus HP
MAIN MANUFACTURING COUNTRIES India 260,000 per year, Germany 44,000 per year, Turkey 40,000 per year, Italy 85,000 per year, UK 58,000 per year, France 16,000 per year. Finland 9,000 Austria 7,000 (Approximate volumes)	India China	India Turkey	India Turkey Serbia Russia Romania Belarus Japan Poland	Italy UK France Germany Russia Serbia Romania Belarus Poland	USA UK France Germany Finland Italy	USA UK Germany	USA
MAIN MANUFACTURERS OF PRIMITIVE TRACTORS Little change or innovation is expected in these countries for 5 years (Minimum Innovation)	India China	India Turkey	India Turkey Serbia Russia	Russia Belarus Romania Serbia			
MAIN MANUFACTURERS OF CONVENTIONAL PLOUGHING-FIRST TRACTORS WITH MODERN FEATURES (Incremental Innovation) Synchro, change on the move gearboxes, safety cabins, 40KPH speeds, electronic draught control, Agco, Deere, N.Holland, Same, Landini, Kubota, Renault		Japan Italy	Japan Italy	Italy U.K. France Germany	USA UK France Germany Finland Italy	USA UK Germany France	USA
Tractor Manufacturers making unusual improvements to ploughing tractors — Cab suspension					Renault of France		
Tractor Manufacturers making unusual improvements to ploughing tractors — 40 KPH Front Axle Suspension					Fendt of Germany		
German Designers consider the Systems Tractor to be the future shape of farm tractors (1972-1999) (Innovation and Invention)				Intrac by Deutz			
				Xylon by Fendt			
				M. B TRAC Mercedes Benz			
					Xerion by Claas		
The World's first fully suspended tractor. (British designer considers that the world of tractors needs a transport-first tractor able to work more speedily on roads and in fields e.g. spreading, spraying) (REVOLUTIONARY INVENTION)			Prototype Trantor	Trantor Series 1			
				Series 2 Trantors			
					Trantor Javelin		
JCB Ltd., of UK pick-up Trantor's fully suspended transport tractor ideas and develops the fastrac range of fully-suspended ploughing-first tractors					Fastrac range of tractors produced in U.K.		