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Developing the Industry Ready Graduate

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Abstract. Pressure on the global food production chain over the next 40 years will be unprecedented – the demand base is predicted to increase from approximately seven billion today to eight billion by 2030, and to over nine billion by 2050; whilst the competition for land, water and energy will intensify, compounded by the effects of climate change on the availability and suitability of agricultural land. This paper highlights how the lean philosophy and associated techniques as developed in the automotive industry can be applied to arable production systems to minimise waste, and reduce energy and resource input into the system, in particular through the advancing technological developments in agricultural robotics. This will in turn influence the curricular needs for course development in the field of agricultural engineering. Students entering these courses in 2017 will not graduate until at least 2021, and will therefore be required to be industry ready in order that they can produce a timely contribution to the global food security challenge. This will require them to be experienced in problem definition and project management as well as lean production techniques; and to be able to adapt continuously to a changing environment and rapid technological advances – in particular in the areas of systems integration relating to sensor technology, power management and communication protocols. The success of a curriculum designed to produce graduates who have the capability to be deemed as industry ready will be reliant not just on ensuring that the technical content meets the needs of the customer, but also on increasing graduate value through the learning environment by the extension of Bloom's Taxonomy to incorporate that of student motivation and self-belief.

Keywords. Capability – Curriculum – Global food security – Precision agriculture – Lean philosophy.

Pour un diplômé opérationnel dans l'industrie

Résumé. *La pression qui s'exercera sur la chaîne mondiale de production d'aliments au cours des quarante prochaines années sera sans précédent, car on prévoit que la base de la demande augmentera, des quelque sept milliards d'habitants d'aujourd'hui à huit milliards en 2030, et à plus de neuf milliards en 2050 ; tandis que la concurrence pour les terres, l'eau et l'énergie s'intensifiera, composée des effets du changement climatique sur la disponibilité et la mise en valeur de terres agricoles. Cet article souligne comment la philosophie allégée (lean) et les techniques connexes telles que celles développées dans l'industrie automobile peuvent être appliquées aux systèmes de production de cultures pour minimiser le gaspillage, et réduire les intrants en énergie et ressources dans le système, en particulier à travers les progrès technologiques en robotique agricole. Ceci en retour influencera le besoin des cursus de développer des cours dans le domaine du génie agricole. Les étudiants qui entameront ces cours en 2017 n'obtiendront leur diplôme qu'en 2021 au mieux, et donc ils devront être opérationnels pour l'industrie afin de contribuer en temps voulu au défi de sécurité alimentaire mondiale. Il faudra donc qu'ils possèdent de l'expérience en définition de problèmes et gestion de projets ainsi qu'en techniques de production allégée ; et ils devront être capables de s'adapter continuellement à un environnement changeant et à des percées technologiques rapides en particulier dans les domaines de l'intégration de systèmes liés à la technologie des capteurs, à la gestion de l'énergie et aux protocoles de communication. Le succès d'un cursus conçu pour produire des diplômés ayant les capacités pour être considérés opérationnels dans l'industrie, reposera non seulement sur l'assurance que les contenus techniques correspondent aux besoins du client, mais aussi sur l'augmentation de la valeur des diplômés à travers l'environnement d'apprentissage en élargissant la Taxonomie de Bloom pour intégrer la motivation et la confiance en eux-mêmes des étudiants.*

Mots-clés. *Capacité – Programme d'études – Sécurité alimentaire mondiale – Agriculture de précision – Philosophie de l'allégée (lean).*

I – Introduction

The global food system is currently able to provide sufficient food to support the majority of the world's population. However, many of the agricultural production systems are unsustainable in their current form and will potentially lead to degradation of the environment, in turn compromising the capability to maintain and increase food production levels in the future to meet the growing population demands – currently estimated as an increase of 1 billion people by 2030 (Foresight, 2011). The *Future of Food and Farming Report* (Foresight, 2011) highlights the need for innovation and research in the field of agricultural engineering to help address this situation, and in particular that linked to sustainable food production.

Students entering onto degree programmes in 2017 will not graduate until at least 2021, and hence will have less than a decade to make a contribution to this global challenge – and it is therefore vitally important that their education ensures that they are industry ready on graduation. Of concern to this is the 2014 *Engineering and Technology Skills & Demand in Industry Annual Survey*, produced by the Institution of Engineering and Technology (IET), which identifies a further increase in the skills gap for graduates to 54%, with the primary shortfalls being lack of practical experience, leadership skills and technical expertise. Furthermore, the *Jobs and Growth: the importance of engineering skills to the economy* report by the Royal Academy of Engineering (Harrison, 2012) indicates that by 2020 the UK will need to grow its number of graduate engineers by 50% just to meet current demand – and this potentially declining number of graduates further highlights the importance of a high-quality, fit for purpose product.

This paper considers some of the emerging engineering technologies that are being developed to help address the global food security challenge, along with the underpinning philosophies that are being adopted as a result of identified synergies with the automotive industry, in order to propose some core considerations for higher education curriculum development activity.

II – Adopting the lean philosophy through use of hi-tech

The current farming system was developed for maximum crop production after the Second World War, and this model has predominantly remained unchanged. However, with the increasing demand on food and water supply to sustain a growing population; the competition for land mass (habitation, grazing, etc.); and increasingly volatile weather conditions, the global farming industry is now aware of the need to produce more with less (Department for Food and Rural Affairs, 2008).

It is proposed that the goal of a sustainable global agricultural system can be achieved by applying lean philosophies alongside the development and implementation of hi-tech equipment. Lean principles (gaining more from less) can be utilised to define the optimal solution for agricultural production processes; with hi-tech equipment facilitating the implementation of these optimised solutions. The hi-tech element provides the ability to reduce process variability and hence reduce waste, through constraining the behaviour of the system by providing controllability and repeatability.

The requirement for efficient increase in output can be compared to the developments undergone within the automotive industry since the early 1900s, introduced by Henry Ford and subsequently further developed by Toyota. This analogy is strengthened further when also considering pressures such as increased competition from global markets, increases in energy prices, tighter legislation and a desire to have less environmental impact.

Through the implementation of flow production, Henry Ford drastically increased manufacturing throughput, but the system did not allow for variety and led to competitors responding with production systems that re-introduced variety whilst maintaining throughput (Lean Enterprise Institute, 2015). The Toyota Production System (TPS) put the focus on the flow of the product through the entire process, along with identification and optimisation of the value stream, and in so doing continually looked to reduce the number of steps and amount of time and information needed to serve the customer. Lean manufacturing is a management philosophy derived mostly from TPS and is a systematic method for the elimination of waste (referred to as Muda) within a production system, defining value as any action that a customer would be willing to pay for (Womack *et al*, 2007).

With the aforementioned increasing competition for land resource, the capability to increase production will need to focus on optimising the value stream and reducing waste. It is therefore proposed that the challenge to ensure global food security by 2050 can be addressed through the application of lean philosophy to arable production systems.

III – Emerging engineering technologies in agricultural production

The philosophy of lean is well-aligned with the definition of innovation – a new idea or more effective process – and which can thus be viewed as the application of better solutions that meet new requirements or existing marketing needs. The robotics engineer, Joseph F Engelberger (1982), further proposed that innovation only requires: a recognised need; competent people with relevant technology; and financial support. It is therefore important that graduates entering employment in 2021, who will be expected to be able to provide innovative contribution to solving the global food security issues, are competent in their ability to identify customer needs and have the technical competencies to deliver these solutions.

These principles can be applied to all aspects of agricultural production. One area in particular that is embracing the process of establishing need and implementing the lean philosophy through the development of advancing technologies is that of agricultural field robots. The use of a robot enables controllable repetition to a task – and it is this accurate repeatability that gives the reduction in variation and hence the reduction of waste within the system. The development of Controlled Traffic Farming (CTF) is a specific example of where the parallel implementation of lean philosophy and hi-tech equipment can be used to minimise process waste. In traditional 'random traffic systems' – where operators are in control and hence can effectively travel wherever they wish – it is estimated that up to 96% of the field area is compacted by tyres (Kroulik *et al*., 2010). Implementing CTF can reduce this to as low as 15%. This is achieved through use of satellite guidance and auto-steer systems (Bochtis and Vougioukas, 2008), which effectively constrain the operator through removing the ability to go where they want – and hence gaining this reduction in variability.

The increasing size of agricultural machines has been driven by the desire to increase the work rate of agricultural tractors (Gasso *et al*., 2013), in order to counter the pressure from increasing operator costs and reduction in the working time window due to environmental factors. This has, however, also had a detrimental effect on the agricultural production process in terms of its efficiency, through introducing waste into the process in the form of excess compaction and the associated loss of energy with its removal. This can be explained by considering the fundamental science that underpins this machinery implementation, which dictates that for every 1kN of draught force a vertical force of 1kN is required – and hence any increase in implement mass requires an associated increase in the mass of the tractor, which in turn increases soil compaction, and subsequently a larger implement is then required to remove this additional compaction. It is estimated that up to 90% of the energy going in to cultivation is there to repair the damage caused by large machines (Blackmore *et al*., 2004). It is therefore clear that the ever-increasing vehicle mass and non-optimised trafficability are significant causes behind increased energy losses and inefficiencies within the system.

As already identified by TPS, an important aspect of reducing waste is to ensure a focus on the core, value-adding aspects of the process and to minimise waste, and this can be translated in to the development of an underlying principle for agricultural production of focussing on the needs of individual plants.

The production process can be viewed as four main stages – crop establishment; crop scouting; crop care; and selective harvesting – with lean philosophy applied to each as follows:

1. Crop establishment – the development of lightweight, autonomous seeding robots

Implementing the underlying principle of reducing waste by not compacting the ground unnecessarily, current development platforms have reduced the ground pressure to less than 40kPa (compared to a human walking footprint of 110kPa) under the contact patch, which minimises agronomic damage even when the ground is at field capacity, and facilitates crop establishment which is not limited by weather condition – and hence increases the working window. Further to this, ensuring that the robot can accurately position each seed through use of accurate navigation technology:

- Ensures that crop position is known, and further that anything else can be identified as a weed by default, and thus facilitating orthogonal inter row mechanical weeding;
- Facilitates use of multiple, small robots to plant crop synchronously – again increasing the working window.

2. Crop scouting

In order to understand the needs of individual crops, it is critical to have sufficient and as near-real-time data as possible. This need is driving the application of advances in sensor technologies to gather this information as follows:

- Visible: Crop cover, growth rates, flooding extent, late emergence, weed patches, rabbit damage, nutrient imbalance;
- Non-visible: NDVI, thermal, multispectral.

The sensors can traverse the crop areas autonomously through Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs), allowing for specific robot applications to be developed such as:

- Phenotyping robots – to facilitate crop trials to evaluate new genotypes
- Crop scouting robots – to provide targeted agronomic measurements, through incorporation of technology such as thermal cameras (to indicate irrigation status), multispectral cameras to provide nutrient status, and Lidar to scope canopy extent and density.

3. Crop Care

The current practice of organic-mechanical weeding is very expensive (approx. £1000/hectare) and needs to be repeated on three separate occasions throughout the growth cycle. The aforementioned precision planting and resulting opportunity for orthogonal inter row mechanical weeding assists to reduce these costs, but developing this principle further is a system called microspraying which also uses this seed map to give initial guidance points, and then uses vision systems to recognise the weeds in the close-to-crop area and then applies chemical in a targeted way solely at these.

A further technological innovation that is being developed is a real-time machine vision system that can destroy weeds by identifying and then heating the growing point of the weed using a laser system – ultimately reducing herbicide application by 100%.

4. Selective Harvesting

It is estimated that up to 60% of harvested crop is not of saleable quality, resulting in significant amounts of wasted product even before the product has reached the point of exposure to the consumer (Farrell, 2015). Again applying lean philosophy, agricultural robots are under development that can identify and selectively harvest only that part of the crop which has 100% saleable characteristics, and ultimately that can grade, pack and sort for size, sweetness, ripeness, shelf-life, etc. at the point of harvest autonomously and hence add value to products on-farm, minimising downstream processing and hence removing waste from the system.

IV – Graduate capabilities

Having previously highlighted the need for graduates to be competent at identifying customer requirements and scoping problem definition, it is evident that they will be further required to be increasingly capable in the technical areas of machine vision, systems integration (e.g. sensor technology, communication protocols, power management), machine intelligence and programming.

There is, however, only a relatively short timeframe to transition a student from 'unknown and variable' when they enter higher education to a graduate who is operating effectively, and it is therefore of importance that the curriculum makes the most efficient use of the time available. It is further evident that the emergence and adoption of technology is advancing at an ever increasing pace and that graduates will reach a period when they will be working with technology that can't be anticipated and hence cannot be taught as part of the curriculum (Fig. 1).

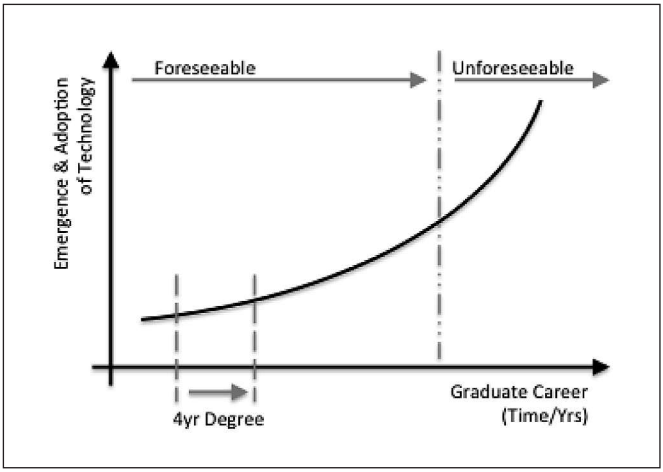

Fig. 1. Increasing pace of technology emergence and adoption vs graduate career duration.

It can be concluded that in order to best prepare graduates who can adapt to current and future challenges, the curriculum must establish a strong foundation in engineering know-how (engineering science, energy transfer, etc.) and must also develop in the students a capability to self-learn that which they will be required to know in the future.

It is therefore proposed that the definition of an industry ready graduate is someone that has the:

- *Capability* to identify customer need and manage projects;
- *Capability* to find, evaluate and synthesise information;

- *Capability* in the underlying core fundamental principles relating to:
  – Technical application,
  – 'Lean' thinking.

Whilst the vast majority of higher education courses would indicate that these aspects are contained within their degree programmes, and hence graduates, the Institution of Engineering and Technology survey (2014) suggests that this view is not supported by employers, and it is proposed that it is the understanding and development of graduate *capability* that is the misalignment. Employers expect that a graduate who is industry ready on graduation will be capable of approaching an unfamiliar task independently, and hence it is proposed that such a graduate has to:

- be capable of undertaking such a task;
- *believe* that they are capable.

Higher education (HE) programmes typically focus on prescribing and assessing specific core content, with this approach primarily supporting the former. Whilst the approach does also contribute in part to building their self-belief, this is predominantly limited to familiar scenarios. It is proposed that this is a factor in the apparent discontinuity between employers and HE providers with regards to their perception of graduates – in that whilst students may be technically capable, they may not be sufficiently motivated or confident to apply themselves to an unknown situation (if students have never experienced learning an unknown, how will they know that they can). A curriculum designed to produce industry ready graduates will therefore need to incorporate the requirement for students to learn and apply technology which they haven't been taught in order to develop their self-belief.

Bloom's Taxonomy is used by higher education curriculum developers as an underpinning framework for developing learners who are able to synthesise and evaluate, and it is often believed that the ability to apply knowledge in this way infers capability. It is further proposed that this model is not sufficient, and that Bloom's Taxonomy needs to be extended in order to achieve capability, through ensuring that graduates also have motivation and self-belief – and that it is these that ensure that capability is actually achieved, and in so doing that graduates have the experience and confidence to produce problem solutions to unpredictable applications (Fig. 2).

V – Conclusion

The realisation of a sustainable global agricultural system will rely on the implementation of precision technologies. The rate of change of technology is such that industry will require input from people who are proficient with the latest developments in these technologies, and hence will be reliant upon students who have been exposed to cutting edge research in these fields.

Students currently considering undertaking a higher education degree programme will not enter the agricultural engineering industry until at least 2021. If the global food security challenge is to be met by 2030, then students entering higher education programmes at this time will have less than 10 years of their early career to contribute in any meaningful way. In order to accelerate the delivery of the food security solution, students therefore need to be industry ready at graduation.

In order to achieve this output, the education process needs to be restructured to facilitate early capability. It is proposed that whilst Bloom's Taxonomy remains a good foundation for constructing a higher education curriculum, in order to satisfy current needs the taxonomy needs to be extended to enable undergraduates to be able to achieve this capability at graduation. To achieve this, curriculum delivery must also nurture motivation and self-belief.

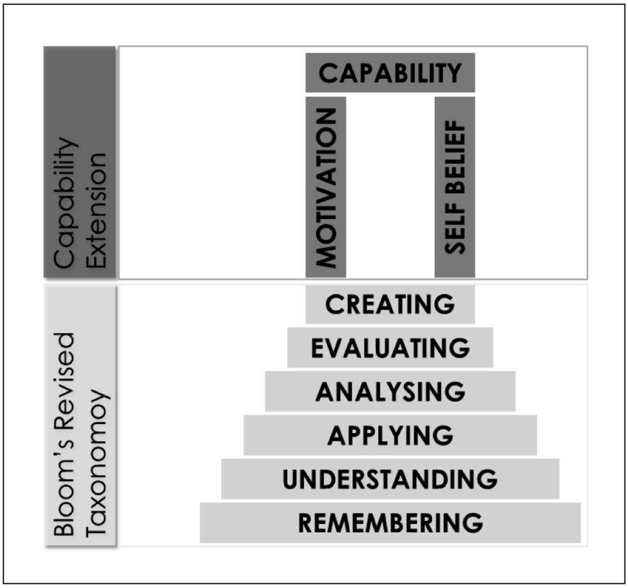

Fig. 2. Bloom's Revised Taxonomy with Capability Extension.
(Source: adapted from Anderson and Krathwohl, 2001).

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