A Mobile Hops Harvester: User-based, Open Source Design and Shared Infrastructure in an Emerging Agricultural Sector

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Abstract. The development of a mobile hops harvester is used as a case study to explore trends toward increased open source equipment development. Theory of intrinsic and extrinsic motivators of innovation are explored alongside current understanding of incentives for participation in open source design practices. Incentives for open source participation are varied and participants in a single product development project may come to the project for very different reasons. The concept of a “design-use community” is introduced as a way of articulating and emphasizing the blurred line between innovation and adoption in the agricultural technology community which the open source movement has highlighted. The authors provide observations of open source modalities in use through a case study of the mobile hops harvester which provides a specific example of when an open source design approach can be successful in developing new agricultural equipment. The harvester has a demonstrated capacity of 120 bines per hour compared to 1 bine per hour per person for manual picking. This rate enables the harvest of a 1 acre yard within 8 hours resulting in optimal harvest timing and improved quality. Assuming a harvest team of 4 people in either case, this translates to a harvest labor cost savings of 97\% or $3,120 per acre at $15 per hour wage (approximately $2 per lb of dried hops (10-20\% of retail price)).

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Agricultural Technology & Collective Innovation

The role of innovation in agriculture has been studied in two broad categories; (1) innovation generation and (2) adoption and use of innovation (Sunding and Zilberman, 2001). The project we'll use as a case study demonstrates both through (1) the development of a smaller, mobile variation of a known mechanical harvesting practice (2) by supporting adoption through collective innovation and (3) through the deployment of that innovation in an open-source mode. In fact, a general result of open source design is to blur the line between innovation generation and use. Designers are users, and users are designers. This phenomenon is echoed in the literature on open source software using the term user-programmers (Bitzer, et al 2006).

The term “open source” has its roots in software development where “source” code is the foundation of design. Other design fields have leveraged the term and it is applied liberally to a design activity in which the analytical basis of the design as well as its materials list, construction approach and performance verification details are provided to the public in some form for reuse, adaptation and improvement. The Open Source Hardware Association is a formal organization seeking to codify the open source modality in the hardware realm.

“Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make and sell the design or hardware based on that design.”

Frazer (2009) makes a clear distinction between “open source” and “public domain,” the former methodology reserving rights to the design and usually involving implied or explicit obligations on the part of the user of the “source” whereas the latter assumes no rights on the part of the “source” supplier.

Sunding and Zilberman differentiate between embodied innovation and disembodied innovation. In other words, an innovation can be embodied in capital goods (equipment, structures, fertilizers, etc.) or be disembodied as a process or practice (integrated pest management, nutrient management, cover cropping, etc.) Furthermore, they suggest recent historical precedent for embodied innovation to be largely the realm of private enterprise requiring strong intellectual property protection while disembodied innovation has been the domain of public institutions including universities.

We will argue that there is a strong basis for open-source movements (e.g. FarmHack) that illustrate embodied innovation within agriculture outside of the private sector. We believe a critical component of this dynamic is the existence of a community of both “designers” and “users”; the “design-use community.” Increased access to design tools and methodologies combined with expanded documentary, publication and communication capability have led to a larger “design-use community” working in agricultural innovations and has amplified their work through social media and other networks such as FarmHack. This community has likely always existed (e.g. farmers sharing innovations with each other and their networks), but its presence is likely heightened due to increased social connectivity over a wider geography and possibly the diversification of the farming demographics (e.g. new farmers transitioning from other occupations.)

A key question we seek to answer is why innovators of agricultural equipment will freely share their developments with others and what we can learn from our experiences with the UVM Mobile Hops Harvester in this area. But it is helpful to review prior work done to understand motivations of both innovation and open-source participation. Identified motivations for participating in open source projects are varied and include everything from signaling for professional opportunities (jobs and career development) to reciprocal altruism (quid pro quo) to the fun of play (homo ludens).

A review of more traditional development methods suggests that the principal motivators for innovation include (1) patent protection for future capitalization, (2) prizes or awards for especially innovative solutions to vexing problems, and (3) contractual compensation for innovative efforts (Sunding and Zilberman, 2000). Others argue that existing patent protection mechanisms actually serve as disincentives for innovation even in light of recent and proposed reform (Jaffe, 2000).

Another possible response is that the design-use community provides an inherent quid pro quo where one innovator shares a solution to one problem with an understanding that they will gain the benefit of another innovator’s solution to a different problem (Lindenberg, 2001). In this way the community shares the burden of innovation and mitigates risk as a result almost independent of economic cost and benefit. Others have highlighted the possibility of a “gift culture”, a more pure altruistic motive on the part of the innovator (Bergquist and Ljungberg, 2001). Some who participate in the open source design practice do so simply for the fun of play (i.e. homo ludens) and satisfaction of identifying an improvement or solving a problem (Bitzer, 2007).

In their assessment of proprietary vs. public domain development of econometric software, Gambardella and Hall (2006) note that collective innovation is generally motivated by one or more of the following; curiosity, taste for science, money, and/or a desire for fame and reputation. Within the academic world, promotion and tenure are also noted as secondary motivations associated with collective innovation. Financial motivations in this
realm are noted as being means to funding further inquiry rather than capitalistic zeal.

In addition to understanding why individuals participate, it is also important to explore the value of the practice more widely to industry and society. There is also value to be had from “crowd-sourcing” intellectual and social capital on agricultural design problems. Allen conducted research on the role of collective invention in the British and American iron industries of the nineteenth century which illustrated the pragmatic benefit of shared research and development among potential competitors (Allen, 1983).

In some ways, the hops industry in the US can be compared to the iron industry of this former study. Both iron ore and agricultural crops can be considered resources of natural origin requiring processing prior to market for the purposes of this study. In both cases, the industry players are in “different regions with different relative price factors.” As a result, it is argued, application of collective invention practices will allow for lower costs and higher “resource rents.” Direct economic competition is necessarily low among collective innovators otherwise there would be a significant disincentive for cooperation. In the case of the iron ore industry, there were only so many locations with resource availability and accessibility.

Furthermore, there was a massive market with little differentiation. It was in everyone’s best interest to extract and convert the product as efficiently as possible. Similarly in the case of hops production in the Northeast US, production is well below ultimate market demand and differentiation is largely based on variety, cultivation practices, post-harvest handling, quality, seller/buyer relations and marketing. Harvest method is not a direct differentiator, but rather an enabler of greater production volume and quality control (due to harvest timing). As such, collective innovation of harvesting technologies and sharing of constructed harvesting machines is supported by the sector.

In summary there are varied motivations for individuals to participate in open source design-use practices and this approach has been demonstrated to accelerate and enhance design functionality of the products it is applied to.

Case Study: The UVM Mobile Hops Harvester

Regional brewers seek local hops for locally-branded, predictably unique, high-quality beers. As a result, farmers have the opportunity to produce a high value crop (4,600-12,900 $/Acre) and improve farm viability (Wilson 2010). The reintroduction of hops to the northeast requires appropriately scaled harvest and processing equipment. This need resulted in a research and development project aimed at delivering a shared, small-scale, mobile, mechanized harvester.

At the start of this research and development project there were no feasible mechanized harvest options for a 1-2 acre hop producer. Handpicking is the most wide-spread current practice which is labor intense and time consuming leading to expense and quality impact due to delayed harvest. Mechanized harvesters are available but are capital-intensive and either require import and modification for use in the US or are built into buildings. Most commercially available harvesters are also stationary, limiting their use to one farm or hop yard or requiring transport of the bulky bines to the harvester. These characteristics make larger, higher capacity harvesters more suited to established, higher-acreage hop yards than are common in this emerging regional market. Early re-adopters of hops in the northeast are eager to have an option for mechanical harvesting of the crop to reduce production costs and improve overall quality.

Beginning in January 2011 a team was formed to address the need for portable, mechanized hops harvest in support of a nascent agricultural sector in the Northeast. This team included an agricultural engineer, hop growers (including farmers of other crops), a brewer, an agronomist, a crop and soil technician and a metal fabricator. The formation of this team represents the first of several decisions that led to a relatively "open" design approach. Inclusion of “non-design” personnel in the design process broadened the inquiry and challenged engineering assumptions. This approach also allowed for rapid exchange of ideas and virtual trial and error of design concepts that might have otherwise taken much longer. Practical and varied knowledge on the part of the diverse team helped to inform design features and conceptual selection in a way a serial design methodology would not.

The design process followed an otherwise standard structure beginning with requirements definition, followed by conceptual or schematic design after which a brief design review was held to select a concept to be used as the basis for more detail design work. But also included forced design review on the part of non-engineering personnel at several important points.

There were several points in the conceptual design period and during design review when very practical and experiential input resulted in significant design choices. In one case the team was discussing the requirement for portability and what exactly that meant when one team member who was a grower interjected by saying,
“Everything is portable. It’s just a question of how portable it is.” It was a useful way of re-framing the question and resulted in better definition of the portability requirement. In another case the team was discussing the question of power source which, up till that point, had been addressed by carrying two options; power take-off (PTO) hydraulics or AC electrical power. One of the growers on the team remarked, “I’d be more comfortable making an urgent repair on hydraulics than I would on electrics. Considering that this crop’s quality is very sensitive to the harvest window, we need to think about how quickly repairs can be made, and who can make them.” The team also performed an informal poll of the hop yards in the region and determined less than 10% had electric power easily available near their yards or even on-site, yet most had tractors with a reasonably sized PTO. In these and many other ways, inclusion of non-traditional designers in the process led to a more refined and customer driven design in the first build.

Like many research and development projects, the design process for this machine was challenged by the timeframe under which it occurred. We began in late winter, when no fresh hop bines were available to use for testing or orientation to the design problem. As a result of this and due to the influence of experienced farmers on the design team we incorporated significant design margin and a high degree of flexibility in the design. For example, we selected hydraulic power because of the ease of troubleshooting and repair mentioned earlier, but also because variable speed control is inherent in hydraulic systems and we were not sure what speed we wanted various sub-systems to operate at. The structural frame was made more robust than necessary in case we found certain members had to be removed to accommodate a design change in the field. We had a good basis for design as the mechanization of hops harvesting has been successfully demonstrated by others and there are, in fact, larger-scale harvesters available for purchase and otherwise well documented. However, scaling the design components down and integrating them more intensely pushed the design practice into new territory. In this case, the experience of farmers was leveraged to accelerate the verification and validation of the design integration in areas where the machine veered from conventional practice. An example of this was the use of several short, but wide, conveyor belts used for moving hops and leaves through-out the machine. Standard practice in conveyor belt design calls for long and narrow belts to ensure better tracking. The space limitations of the design platform necessitated short and wide belts in our case and the inclusion of both and engineer and farmers on the team allowed for a non-standard solution to the problem which involved v-belt tracking, increased belt span support and fencing.

To date, 255 people have downloaded the plans for the machine and 5 others have built harvesters at least partially informed by this work. This harvester pulls a complete bine (central bine/vine, leaves and cones) through a section of stripping fingers that separate the cones and leaves from the bine. The cones and leaves are conveyed to a secondary sorting section with inclined rolling “dribble belts” against which the leaves lie flat while the cones roll backward down the belts. In this way the machine takes a loaded bine and produces two separate output streams of cones and leaves.

Conclusions

In considering the forgoing summary of open source incentives and benefits and in reviewing our application of the practices to a mobile hop harvester we observe the following.

1. Market Demand - Regional hops production in the northeast US is a re-emerging industry that does not have
the infrastructure or capital to adopt centralized mechanized picking, but for which hand picking is prohibitively time and labor intensive. Thus, there is a market opportunity for an alternative solution that strengthens the business viability for this industry.

2. Poor Alignment of Standard Design Methodologies - Traditional equipment development methodologies and schedules were not well aligned with the design problem. Given the varied stakeholders (design-use community), compressed timelines involved, and need for rapid deployment, we considered open source development as the design approach. Specifically, we made the machine details open source, invited feedback via a discussion forum and traditional means, and solicited willing beta testers to use the machine for harvesting. This is very similar to most open source software development, but it does not have significant documented precedent as a product development method in universities or in agriculture.

3. Shared Risk and Reward - The risk was shared among the design team and the early adopters, who took on non-trivial burden of design verification and validation. In the words of a well-known open source participant, Linux instigator, Linus Torvald, “Release early and release often.” Releasing a basically functional but imperfect design to the open source design-use community puts more designers on the team. There is a modified transaction model in which risk is shared in the community due to the evolving nature of the design, but reward is also shared and likely is shared earlier than otherwise. The open-source nature of the design delivery allows for incomplete designs to be released sooner under the assumption that the user bears the burden of verification and validation.

4. Enhanced Design Clockspeed – As has been demonstrated in the open source software development world, early adoption and adaptation of the design among multiple machine replicates allowed for multiple parallel generations of design enhancements to be completed, further accelerating design evolution. Part of the design evolution was the ability of early adopters to customize the design for their use. Like sharing of verification and validation risk, this shared the development cost between the design team and the early adopters. The larger number of field sites we were able to run tests at enabled us to receive feedback from the design-use community in addition to the machine users. Effectively, we were able to expand the scale of our verification and validation farther through the value stream. We saw sharing of lessons learned as the early adopters formed a design-use community.

5. Rate of Adoption – The open source approach has enabled others to replicate the design and therefore incorporate mechanical harvesting into their operations. The mobile nature of the machine also makes it feasible as a piece of shared infrastructure. This has enabled potential replicators to actually try the machine before committing to building one. It is unclear whether the rate of adoption we have observed is faster than it would be otherwise (e.g. purchasing a machine). It should be noted, however, that a sizable portion of the inquiries about the machine about direct purchase of an already fabricated machine rather than inquiries about use of the design documents to fabricate one. This suggests a hybrid mode of open source design and serial production is likely possible in some form. This is a point of departure from open source software development modalities since fabrication and assembly practices differ significantly in equipment and hardware when compared to software. In fact, an example of this practice can be found in the Arduino microprocessor platform. The design documentation for the processor is open source, but users can also buy assembly kits or fully assembled controllers for immediate use. Further exploration of this topic is left to future work.

References


