Crowd wisdom drives intelligent manufacturing

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Abstract

Purpose – A fundamental problem for intelligent manufacturing is to equip the agents with the ability to automatically make judgments and decisions. This paper aims to introduce the basic principle for intelligent crowds in an attempt to show that crowd wisdom could help in making accurate judgments and proper decisions. This further shows the positive effects that crowd wisdom could bring to the entire manufacturing process.

Design/methodology/approach – Efforts to support the critical role of crowd wisdom in intelligent manufacturing involve theoretical explanation, including a discussion of several prevailing concepts, such as consumer-to-business (C2B), crowdfunding and an interpretation of the contemporary Big Data mania. In addition, an empirical study with three business cases was conducted to prove the conclusion that our ideas could well explain the current business phenomena and guide the future of manufacturing.

Findings – This paper shows that crowd wisdom could help make accurate judgments and proper decisions. It further shows the positive effects that crowd wisdom could bring to the entire manufacturing process.

Originality/value – The paper highlights the importance of crowd wisdom in manufacturing with sufficient theoretical and empirical analysis, potentially providing a guideline for future industry.

Keywords Big Data, Crowd science, Crowd wisdom, Intelligent manufacturing

Paper type Conceptual paper

1. Introduction

Intelligent manufacturing is the development and implementation of intelligent machine in manufacturing. It refers to the use of production process technology that can automatically adapt to changing environments and varying process requirements, with the capability of manufacturing various products with minimal supervision and assistance from operators (Yang and Ding, 1992; Qu and Liu, 2009).

To achieve the goal of intelligent decision-making in the process of manufacture, an urgent need is to find the source of intelligence. Thanks to the internet era, there never has been a time like this when enterprises can access such a massive crowd, constituted by

individuals with various backgrounds, coming from different countries and districts, and thus, it is reasonable to come up with the idea to exploit the crowd of diverse strangers, which is a desired intelligent crowd. In fact, consumer-to-business (C2B) mode is calling for industry to make good use of crowd wisdom.

In this paper, we propose to use the concept of crowd wisdom for working as the brain of manufacturing. Many examples (Surowiecki, 2004) prove that a qualified crowd would make wise decisions and accurate judgments with the abundant information collected by the consisting individuals. Thus, we apply the theory onto manufacturing, pointing out that with various data contributed by the crowd, including customers especially, manufacturing decision could be obtained, and we try to explicate the reason why Big Data is key to intelligent manufacturing in the perspective of crowd wisdom.

The rest of the paper is organized as follows. Section 2 explicates the base of crowd wisdom, including the qualification for an intelligent crowd and the source of its wisdom. Section 3 introduces the crowd participation in detail and how it contributes to intelligent manufacturing. Section 4 strengthens our points with several cases where enterprises utilize crowd wisdom, which is of great help. Section 5 concludes the paper.

2. The principle of crowd wisdom
Predecessors' works revealed an amazing fact: the wisdom of crowds is incredibly surprising. In 1906, a British scientist, Francis Galton invited 800 participants to evaluate the weight of an ox. Some of the participants are experts on agriculture, while the others are sheer laymen. The average evaluation of the crowd is only one pound less than the real weight (Surowiecki, 2004).

Individuals make their own judgments on the same topic independently. When the judgments aggregate, the crowd's judgment would be incredibly close to the fact. In fact, the aggregate judgment is often accurate even in the case of predicting the future. First, we analyze the key principles of crowd wisdom.

2.1 Characteristics of intelligent crowd
After aggregating individuals' judgment, we will obtain a good judgment. The approach is seemingly too naïve to be real.

But unfortunately, not all crowds possess such sharp judgment. J. Surowiecki elaborated the necessary characteristics of a crowd with great wisdom in his work, that is, under decentralization system, a diverse crowd constituted of independent individuals would make good judgment (Surowiecki, 2004). Figure 1 shows the characteristics and how they are related to each other.

The base of crowd wisdom is the private information within an individual's judgment. The information from each individual partly depicts the fact more or less. When a large amount of information from the individuals is aggregated, those pieces of information could counteract as well as complement each other. Thus, mistakes cancel out and the crowd possesses the entire information about the truth. This guarantees the authenticity of the crowd's judgment and the decision derived.

The wisdom comes from the crowd, as the crowd owns abundant information. Ultimately, the wisdom comes from the information. And the reason why we request the diversity of crowd is that we have to ensure that the information from the crowd is truly comprehensive rather than duplicates of the same information in diverse expressions.
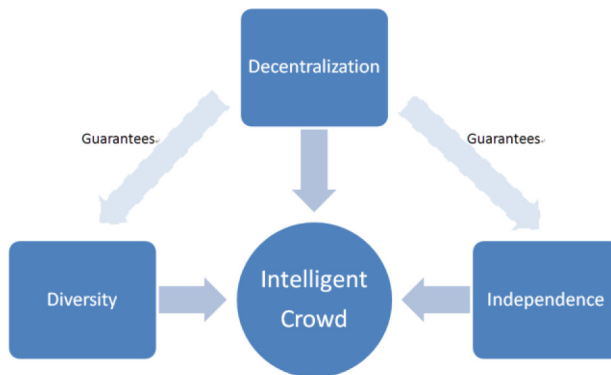
Figure 1.
Characteristics of
intelligent crowd

2.2 Diversity of the crowd

Generally speaking, making a crowd judgment is a two-stage process. The first stage is searching for a judgment pool, which is the collection of each individual's own judgment using his or her private information. And the second stage is obtaining a crowd judgment, by means of aggregating the judgment of every individual in the crowd with a particular technique.

It is obvious that the more extensive the judgment pool, the more preferable it is, as a good judgment is more likely to be included, enter the second-stage and impact the final judgment rather than being ignored regretfully.

Hence, now our problem is how to extend our judgment pool?

Because judgment originates from individuals' analysis and thinking, we need people with unlike thought patterns, experts in different domains, owning diverse experience and background to be involved. Individual differences ensure the diversity of information and judgment.

2.3 Independent individuals

Independence guarantees that a wrong judgment from an individual would cause no impact on other individuals in the crowd. Mistaken judgments can counteract in the process of aggregating; therefore, the accumulated information is still correct.

Besides, independence encourages individuals to explore new private information, rather than be sedentarily satisfied with the public information. Apparently, new information is advantageous for extending our judgment pool.

Here we arrive at a paradox. If the crowd's judgment is intelligent, why do we not just simply adopt the crowd's judgment instead of contemplating our own judgment, which is likely to be a wrong one?

The answer may sound contradictory: the mistakes of individuals make the crowd smart, thus leading to a good crowd judgment. But when individuals begin adopting the crowd's judgment, the crowd becomes sluggish, while the individual is gaining wisdom.

Making a judgment is never a short-term process, neither is the evaluation of a judgment. A good process should be like this: individuals make judgments independently, then the crowd wisdom works and a good crowd judgment is obtained. After a period when a large number of individuals adopt the crowd judgment, defects of the judgment would gradually emerge or someone would figure out a new judgment. Then, the massive followers would stop adopting the existing judgment and a new round of independent exploration ensues.

Perhaps as time goes by, the defects would be exposed to the public, so the process proceeds. Nevertheless, generally, a promoter, the one who figures out a new judgment when most of his or her peers adopt the crowd's judgment, plays a role. Those insistent independent thinkers propose a new judgment, break the original stagnant state of the crowd and weaken the authenticity of the prevailing crowd's judgment. More individuals are encouraged to cease following and pay more attention on private information and personal judgment. The promoters help us from drowning in the crowd wisdom.

2.4 Decentralization system

The concept of crowd is always related to system design. After all, the art of management is designing an appropriate system, one that vitalizes the crowd.

In our context, we expect a system that can motivate the individuals to search for diverse judgments, maintain individual independence and ensure that the final crowd's judgment is indeed an aggregated one, instead of coming from a dominant individual.

Many precedents prove the superiority of a decentralized system in the aspect of ensuring the three very critical points above. A decentralized system is one that is absent of the center of power.

In a system with distinct powerful members, for example, in a centralized system, various influences from dominant individuals can be a problem that cannot be neglected. Individuals may judge no longer based on facts, but reluctantly, indifferently or blindly follow the decision of superiors, experts or elites.

The undesirable situation defies the demand for independence. When dominant individuals spread their influence, they publicize their private information, which subtly influences the choice of other individuals. Even worse, a wrong judgment from the dominant individual would lead the whole crowd into an abyss.

Moreover, a blind crowd can neither be tagged as diverse nor be provided with a diverse judgment pool, as individuals can hardly be expected to give unique or distinct judgments. It is predictable that the judgment pool would be partial.

A centralized system stifles the diversity of the crowd. The crowd may come to an agreement promptly; meanwhile, they may enter the dilemma of group think (Zhang *et al.*, 2010), where everyone tries to obey the majority and avoids proposing new angles or objection. Such a crowd may extremely believe in the correctness of crowd judgment and strongly object to any criticism or advice from the outsiders, as they deem that the final judgment is a real crowd wisdom while actually it is not. A decentralized system helps us to avert such a plight. At least, during the first stage, a decentralized system ensures that the judgment from an individual is independently made, thus guaranteeing the diversity of the judgment pool. Therefore, the final judgment will not be greatly influenced by some individuals in the crowd.

3. How crowd wisdom participates in manufacturing?

Figure 2 gives an overview of how crowd wisdom participates in the manufacturing process. The manufacturing process could be generally divided into requirement eliciting, design, trial, production, marketing and upgrade. Each phase is confronted with a main judgment and decision, which is specific to this phase and critical to the entire manufacturing procedure. A system accomplishes the decision-making tasks with the help of a large amount of data that was contributed by the crowds. Thus, crowd participation is vital for accurately judging and making smart decisions, and the influence exists throughout the whole process.
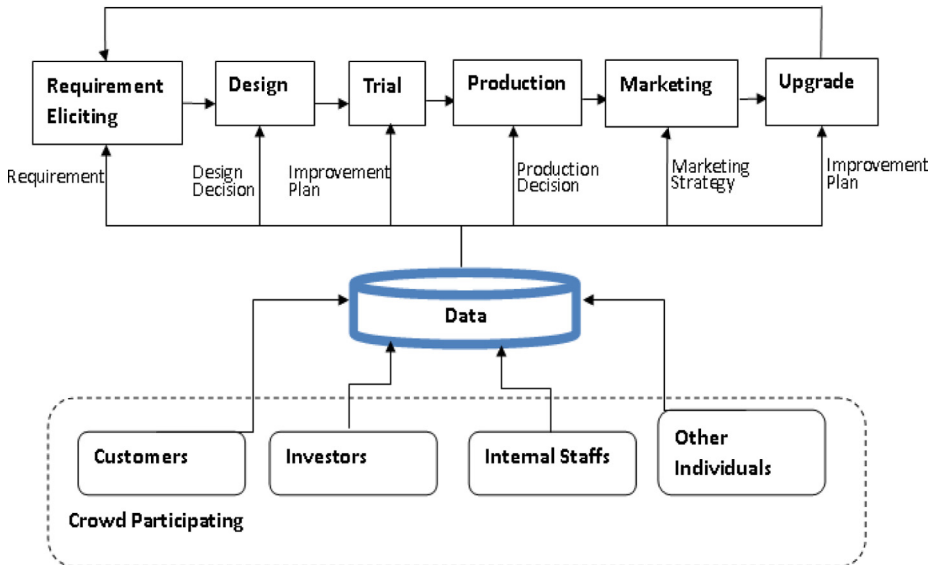
3.1 Manufacturing from customers, for customers

The concept of intelligent manufacturing is tremendously extensive, among which product innovation is an important proposition. Normally, user requirements point out the direction for enterprises. Nevertheless, it is not easy for enterprises to fully understand users' real demands. Therefore, it is common that contrary to its over-rhetoric advertisement, a new product is of no novelty at all, but full of trivial so-called new functionality.

To solve the dilemma, a C2B mode was proposed. The core of C2B is that customers bring value to the company, involving consumers co-creating ideas, product or service concepts and solutions with a company through the social media (Hart, 1991). Customers put forward their dream product and then businesses produce accordingly. In the generation of intelligent manufacturing, the traditional business-to-customer (B2C) mode would naturally transform into the bottom-to-top C2B mode, where users' desires substantially dominate manufacturing. There is no need for businesses to devise new products painstakingly with its own innovation team and then persuade the customers to buy their stuff, as they only produce what customers desire for. Obviously, it is a much more efficient mode, and it promotes personalization and customization, which are also key words in the theory of intelligent manufacturing.

A distinction between B2C and C2B is the involvement of customers' opinion. It is reasonable to ascribe the advantage of C2B to its positive employment of the power of customer group, in other words, the wisdom of crowd.

3.2 The intelligent crowd

The explanation above may create an illusion: intelligent design is a really simple task for enterprises, as all they would do is to ask customers, and then adopt customer's choice. It seems that innovation departments can be disbanded forever.

There is a possibility that the design process of some products is that simple. For example, many brands had encouraged their customers to design and vote, and they

produced the most popular design. But in most cases, the process is more complex, and the intelligent crowd involves more individuals than customer group solely.

Innovation departments are needed. Most of the enterprises cling to their own characteristics, such as the front design of a BMW series. Internal staff's judgment would bring in such consideration and thus the final judgment would be a balance between customer needs and the enterprise style.

Another group of important participants includes investors, or the management of enterprises. Judgment from investors would take business factors into consideration, reflecting a new angle in the final crowd judgment.

A relative concept is crowdfunding (Jussila *et al.*, 2016), that is, a presented idea appeals for various investors' funding on internet, and only with adequate funding can the project proceed. This is similar to the concept of "voting with feet" in the discipline of corporate finance, where you express your judgment by buying or selling stocks. Similarly, investors provide their personal judgment in a financial way.

Besides, potential contributors may include various seemingly irrelative individuals not belonging to the groups above. Consider an example of car design: mechanics and washers can provide useful information about car design. For example, the existing design with superfluous details causes inconvenience for maintenance.

3.3 Data reveal wisdom, but crowd creates data

Now we have to answer a question: When aggregating the judgment from individuals, what are we actually aggregating? Are we only aggregating the judgments?

We mentioned that "the base of crowd wisdom is the private information within individuals' judgments". What we actually aggregate is the information conveyed in the form of judgment. However, when individuals are unwilling to express their judgments or inconvenience in using their private information, can we skip the step of an individual making judgment but aggregate information directly? Can we still obtain crowd wisdom in this way? Can we paraphrase "the wisdom comes from the crowd, as the crowd owns abundant information" as "the wisdom comes from abundant information"?

Sure, we can. To some extent, we can simply ignore individuals' judgments. Individuals' judgment ability cannot explain the superior performance of the crowd's judgment. The good performance is the result of the quality of input information, precisely, whether the information is abundant and diverse enough to depict the fact wholly.

And, thus, we can explain the importance and attention the public puts on Big Data, which is a hit in the past years. The industry widely highlights the necessity of Big Data in the on-going revolution to intelligent manufacturing (Krumeich *et al.*, 2014). A more common expression is "Big Data drives Intelligent Manufacturing" rather than what we propose here. But we must understand the reason why Big Data could provide us with smart judgment and decision. In fact, Big Data is the abundant information generated by individuals from the crowd, including the netizens (internet citizens) crowd. And thus, as discussed earlier, the truth is depicted and the reliability of an aggregated judgment based on the data is well guaranteed. Therefore, we can conclude that the wisdom of Big Data is the wisdom of crowd.

It seems somewhat inconsistent with what we described earlier. An individual's judgment is no longer necessary, but we still rely on the individuals to explore abundant and diverse information for the crowd. And, thus, the final crowd judgment still reveals crowd wisdom.

3.4 Data collection and crowd collaboration

Information is far more comprehensive than user requirements solely. And, thus, what we ask for from the individuals in the crowd extends beyond their own judgment. Particularly,

customers are expected to contribute personal habits of consumption, evaluation of the purchased products and so on. Various, ordinary, even seemingly unrelated information may tell an incredible business secret when they are aggregated. And that is why many enterprises are eager for user information, even when the information is of no relevance to its business.

The process can be described as collaboration. Information from a single individual is partial, but when information is obtained from all the individuals working as a whole, it is complete enough for an accurate description of the truth, assisting manufacturing decision further than providing inspiration and design. For example, with abundant feedback, decisions such increasing or reducing production can be made automatically, and defects' feedback could be collected and used to guide better next-generation products. Therefore, the production process would improve and management technique would get upgraded.

In a word, the more individuals in a crowd contribute, the more powerful of the crowd wisdom, and thus, the better intelligent manufacturing would function.

3.5 Aggregation: the emergence of wisdom
So far, we blur the boundary between judgment and decision. The explanation for this vagueness is that a smart decision is usually derived from an accurate judgment to the target and thus they are the same in essence. Also, we have not explicitly explained how a crowd makes a judgment.

In fact, we would not and could not explore how the crowd decision is made. This is a question of how to deal with the pool. We guarantee you that wisdom does exist in the pool. But as for how to extract the wisdom, the techniques vary.

In free markets, price is the method, while in diverse evaluation experiments, which J. Surowiecki mentioned in his book, statistical methods such as counting votes are recommended. A point worth noting is that the method should ensure that all the information would be made good use of and unified to work as a component of the whole (Surowiecki, 2004).

For some problems, the technique is naïve and explicit, just as what we mentioned above, while for others, it involves more advanced technologies, which becomes the subject of another discipline, that is, artificial intelligence (Meziane *et al.*, 2000), an art of extracting information. Artificial intelligence, along with all of us, would be indispensable in the trends of intelligent manufacturing.

4. Crowd wisdom drives manufacturing: several case studies
In the following paragraphs, we will study several cases, where enterprises successfully use crowd wisdom.

4.1 Crowd wisdom inspires design
In February 2016, Haier launched a water heater with purification functionality. The sales of the new heater surpassed 10,000 in only 21 days (Xu, 2016).

Not long ago, Haier received complaints from over 300,000 netizens about unclean bathwater. After consulting with the netizens, Haier was inspired to develop a new series of heaters. The new function of these heaters includes full purification capacity, not only eliminating the bacteria but also removing the residual chlorine in tap water and sediment (Su, 2015).

Complaining customers must be far more than 300,000 and the contents must be diverse. Entering Haier's official website, you will notice that some complain about the price, while some are dissatisfied with the inconstant temperature. But the 300,000 must be the majority

and thus in this way statistics work. A simple aggregate of individual judgment leads to a crowd judgment: purification functionality is a good idea.

Crowd wisdom efficiently facilitated Haier on the issue of novelty, thus researchers and developers can focus on these techniques.

4.2 Crowd wisdom streamlines production

In Zara stores, there are cameras hidden in every corner and the staff carry personal digital assistants. The purpose is to collect customers' every single piece of advice, like preference toward patterns or the size of buttons. Besides, Zara's online stores contribute more data. Zara has opened six online stores in Europe. Every day, the collected information would be aggregated to Zara's internal global network to facilitate the designer. Once the design is determined, it would be immediately sent to the production line.

The data help a lot. Making production decision based on collected data greatly reduces inventory, and thus reduces costs. Also, an analysis of the data reveals domestic prevailing color and other information which help discover target markets and design.

The Inditex Group, the parent company of Zara, prides itself to deliver quality merchandise in as little as three weeks from its own factories. Designers develop new models daily, sometimes three or four a day, which are then reviewed and put into production (Chen, 2009).

Valuable customer information is not only applied in the manufacturing but also in all departments throughout the Inditex Group, including customer service centers, marketing departments, design teams and production lines, etc. These massive data greatly help on the application of the vertical integration principle inside Zara and also contribute to the measurement of KPI (Key Performance Indicators) for all departments..

Further, the optimization based on positive utility of massive data brings substantial profits. In fiscal 2014 (ended January 31, 2015), the company had sales of \$19.7bn compared to Uniqlo \$16.6bn, Gap \$16.4bn, Mango \$2.1bn. Inditex sales increased 8%, far stronger than its competitors (Loeb, 2016).

4.3 Crowd wisdom creates business opportunity

A challenge for enterprises is that not all the customers are willing to provide their information. Obtaining a piece of advice may be easy, but for more private information, such as birth, age, daily routine, many people would regard it as an invasion of privacy and strongly oppose it.

But because enterprises are desperate for the information revealed from customers' data, they have to resort to tricks and strategies. The strong motivation drives enterprises to create new business modes, which enable them to establish intimate relationships with their customers.

Nike transformed its sports shoes into wearable devices, and connected user data to Nike + fitness social network via shoes or the wristband sensor. The shoes would automatically record users' training data while the iPod stores and displays the data, including motion date, time, distance, calories burned, etc. Users upload data to the Nike community, share and discuss with friends. Members in the community can compare, analyze and set targets for their own training (Wu and He, 2014).

Nike accesses users' data by means of encouraging them to upload their training records. With an increasing number of people using its products, Nike learns about the best jogging routine in major cities, and even gets a list of songs for those who love to jog.

These data, if Nike plans to organize a marathon, to advertise its new products, will prove to be of great help. Besides, the abundant data play an important role in the effort to understand user habits, for improving products, etc.

5. Conclusion

Wisdom is derived from crowds, or, to be precise, from the information contributed by the crowd. Information, in the forms of various data, may be seemingly unrelated or useless, but actually it tells a lot when aggregated, which we proved with several real cases. Crowd wisdom assists, or even partly substitutes, humans to make judgments, which could be well applied to manufacturing, where plenty of judgments and decisions are made. In the blueprint of future industries, crowd wisdom would surely drive the development of intelligent manufacturing.

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