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Utilizing Collective Intelligence to Combine Theory of Constraints with Lean Six Sigma

Jon M. Stein[1]

[1] Louisville, Kentucky, United States

Correspondence: Jon M. Stein, Louisville, Kentucky, United States. E-mail: oneday2one@icloud.com

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Abstract

This paper introduces a tool that embeds the emerging science of Collective Intelligence (CI) within the field of continuous improvement, effectively combining Theory of Constraints with Lean Six Sigma. This new methodology takes advantage of the existing CI within organizations, systems, or geographical areas and utilizes that CI to combine Theory of Constraints and Lean Six Sigma into a streamlined, continuous improvement system referred to in this paper as TOCLSS/CI. Accurately measuring CI offers access to a collective insight that may otherwise be undervalued or ignored. Effectively measuring CI also represents a key step in resolving a primary challenge within Theory of Constraints, specifically regarding primary constraint identification. By harnessing the power of CI through the creation and submission of a single, multiple-choice, simple-question survey utilizing a multi-phased approach; TOCLSS/CI offers a solution that directly resolves the challenge of primary constraint identification with a high degree of focus. This frees the existing tools of Lean Six Sigma to fully address any constraint identified and clears the way for the process to become continuous with the discovery of a new primary constraint. Further research is needed to verify results when utilizing TOCLSS/CI, as well as an exploration using this methodology over more than one organization at a time (i.e., across broader industries or supply chains). Utilizing TOCLSS/CI need not impede any current or existing continuous improvement system, minimizing any burden upon any organization that is willing to adopt it.

Keywords: continuous improvement, collective intelligence, lean, process improvement, six sigma, theory of constraints

1. Introduction

Collective intelligence (CI) represents a vast and untapped resource in society and within every organization (Leimeister 2010). This paper will show how CI can function in the initial discovery phase of an optimal continuous improvement program for any integrated system. The tool proposed in this paper accepts Theory of Constraints (TOC) as a general unifying theory for Operations Management (Gupta & Boyd 2008). Research suggests the most promising results involve a combination of TOC with Lean Six Sigma (TOCLSS) (Demchuk & Baitsar 2015, de Jesus Pacheco 2015, Ahmed 2019). CI is useful because, in the language of TOC, every system has at least one primary constraint directly impeding progress (Hamalainen & Saarinen 2004, Dettmer 2005). Utilizing CI can leverage the focus of the problem-solving tools of Lean Six Sigma by identifying the system or process within the organization that contains the primary constraint representing the most powerful impediment to its progress. CI can directly address the initial step of constraint identification by harnessing the entire collective insight of the organization, and therefore assist in the discovery of the primary constraint so that time and resources are not wasted on solving a problem that likely carries one or more fundamental constraints. The purpose of developing this field is to make the holistic integration of continuous improvement methodologies more effective and efficient. While Lean Six Sigma is cited specifically in this paper, it is further assumed that researchers will apply data science when encountering data sets of significant size or proportion (Zwetsloot, Kuiper, Akkerhuis & Koning 2018).

2. The TOCLSS/CI Approach for Uncovering Primary Constraints

The specific tool proposed in this paper (TOCLSS/CI) primarily focuses upon the preexisting CI within an organization or system. This minimizes cost by maximizing the collective insight and value of an already existing asset. Currently, every organization or integrated system of people contains a vast resource of CI, regardless of whether or not the potential of that CI has been realized (Leimeister 2010). This CI could be the

most valuable, under-utilized asset within such systems or organizations. TOCLSS/CI takes advantage of this existing CI by utilizing it to discover the primary constraint(s) holding such organizations back from progress or enrichment. This process of discovery is conducted through sampling via a single-question, multiple-choice survey. The intent of this survey's design is to protect the purity, accuracy, and authenticity of the measurement it intends to take. Therefore, the primary obstacle then becomes bias or lack of engagement (Draugalis & Plaza 2009; Choi & Pak 2005).

To maximize the collective engagement of the sample population, TOCLSS/CI functions optimally when implemented as a survey asking a single multiple-choice question. Implementing a one-question survey minimizes the cost of time and attention requested of its respondents and therefore maximizes the probability of buy-in and engagement in the process. The primary question on the survey should be worded as simply as possible. For example, *"Which area of this organization is in most need of attention?"* The question facilitates the subject's reflection of their holistic experience of the organization, enabling them to identify the primary sector of that organization within which a primary constraint most likely exists. The simplicity of the question should not require additional explanation; e.g., what a constraint is. A simple, direct question ensures maximum communication between the researcher and the respondent and is only further crystalized when the respondent is offered multiple answers to choose from (Foddy 1993). Research indicates that 8-12 choices are viewed as psychologically optimal by respondents, with 15 or more creating an experience of choice overload and 6 or fewer creating an experience of too few choices. Optimizing choice count further maximizes the engagement of those sampled (Reutskaja, Lindner, Nagel, Andersen & Camerer 2018) (Note 1). To minimize bias, answer choices should comprise an equal subdivision of the entirety of the organization. This maximizes the chance of uncovering the primary constraint and identifying the area containing that constraint. The equal subdivisions should be named or otherwise labeled and offered as possible answer choices to a survey containing a single multiple-choice question. The slices, areas, or aspects of the organization identified within the multiple-choice answers should be simple and as easy to understand as possible to minimize potential inaccuracies due to respondents misunderstanding what those answer choices represent. Optimal sampling methods should be chosen to further minimize bias relative to the unique conditions of the population being sampled, including cluster sampling or stratified sampling where needed, or even targeted sampling to prevent the sample from being weighted by respondents not fully exposed to the operational breadth of the organization (Etikan & Bala 2017). As an example, in a large grocery store chain, members representing store management may be an ideal sample target. Store managers are exposed to the full spectrum of operations, with the store as the center of customer interaction and therefore the arm of operational purpose for the company. Clerks or cashiers may simply not have full exposure. Similarly, high-level corporate managers and executives may carry preconceived biases due to their primary roles/responsibilities or may simply have a limited scope of primary constraints due to a lack of full exposure.

3. Utilization of Multiple Phases to Increase Accuracy and Specificity

While the initial phase of sampling is important, the strength of TOCLSS/CI involves multiphase sampling where additional rounds of sampling or measurements are collected based upon the results of the preceding round. Within these additional phases of sampling, the same target population sampled in the initial phase need not be the same target for subsequent phases. This is due to the same reason the initial phase's targeted population for sampling was chosen: to minimize bias while maximizing the accuracy of the measurement of the collective insight of the sampled population. Using the grocery store chain example, if the results from the initial phase of sampling of store management revealed that the primary area of the organization needing attention involved the supply chain, then the next phase of sampling should target those members of the organization fully exposed to the entirety of the supply chain, choosing sampling methods that minimize bias (Etikan & Bala 2017).

Additional phases of sampling can continue until a desired level of specificity or focus is achieved (Figure 1). Where or when exactly to draw this line will include important factors such as time constraints, budget limitations, and/or resources required for project turnaround. Existing research on CI can also be utilized to determine where to draw the line. Specifically, Vercammen & Burgman presented individuals with multiple-choice questions and found that the CI of randomly organized groups of as small as six respondents created via bootstrapping exhibited IQ scores one standard deviation greater than those held by the average individual respondent (2019). Therefore, it may be counterproductive to conduct any phase of sampling smaller than sizes that approach six or less due to diminishing returns. Once the final phase of sampling is complete, with the results revealing or exposing the specific area or process of the organization harboring the primary constraint, Lean Six Sigma can then initiate the problem-solving/solution-creation process (Note 2).

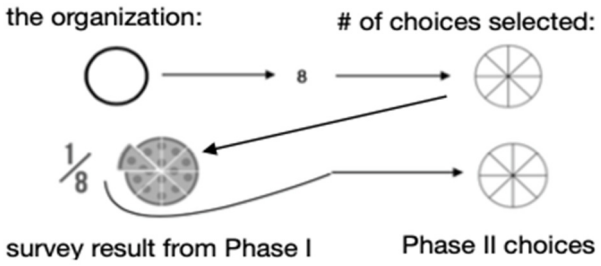

Figure 1. Multiphase Sampling in TOCLSS/CI

After a solution addressing the primary constraint is uncovered or created and project management is utilized to implement the solution in a controlled way, ensuring its proper, complete, and stabilized execution (Note 3), a new TOCLSS/CI-cycle can then be initiated. Beginning a new Phase I survey after the completion of one full TOCLSS/CI-cycle accomplishes two things: it begins the process of identifying or re-identifying the specific area of the organization containing the primary constraint, and it measures the success of the solution implemented from the previous cycle. If the result from a new Phase I survey still identifies the same area of the organization as harboring the primary constraint, the solution from the previous cycle may have either not fully resolved the organization's primary constraint or may have dealt with a specific area of the organization that contains two or more independent roots, each with their own primary constraint directly impeding the organization's progress. Likewise, if the results of a new Phase I survey do not indicate the same area of the organization identified in the previous cycle's Phase I results, this can be viewed as a measurement of the success of the solution implemented from the previous cycle. Of course, a pre-requisite to ensuring the same primary constraint isn't incorrectly re-identified involves ensuring any solution garnered from the initial TOCLSS/CI cycle has been fully implemented prior to the initiation of a new Phase I survey.

4. An Exploratory Analysis of TOCLSS/CI Applied Upon a Geographic Area

An existing company or organization open to, or interested in, experimentally testing the application of TOCLSS/CI in practice was not discovered. To carry forward with research in the actual application of TOCLSS/CI, applying this methodology upon a geographical area was selected. Thus far, an explanation for the utilization of TOCLSS/CI has been shown how it can be applied to a contained system or organization. An exploratory analysis was undertaken to show how this same methodology can be applied to a geographical area. This capability can be useful to multiple areas of interest. For example, a marketing team can utilize the discovery phase of TOCLSS/CI to uncover a primary constraint that a new product, process, or service could address specific to the population of the area selected (Shahin, 2008). This could equally be of benefit to the government or other political or social organizations such as research groups, think-tanks, etc. Furthermore, such geographical research may be useful for more general purposes within various academic fields as it relates to uncovering hidden constraints within areas under academic consideration.

An unfunded test was constructed to explore the practicality of the use of the TOCLSS/CI on the geographic area equal to the city of Louisville, KY in the United States. This is a city harboring a population of 617,638 as of 2019. While the city of Louisville was chosen, the geographic application of this methodology could be applied to any other city or geographic area of any population.

A question was chosen to be presented to the public within the selected geographical area, followed by a numbered list of twelve possible answer choices. The question chosen for the survey was, "What one issue are you most passionate about?" This exploration chose a political interpretation of the question for answer generation due to political issues in general covering every area of societal concern for most citizens. The wording of the answer choices was controlled to create as minimal of a political identity as possible regarding any potential reason that any individual answer may be selected. There was also an attempt to control the total number of answer choices while ensuring that every potential area of interest was covered.

The sampling methodology utilized in the initial discovery phase involved the creation of a physical sign of the approximate size of 75 centimeters wide by 115 centimeters tall. The sign maintained a white background with clearly legible, black block lettering and was inscribed with a question and corresponding answer choices to choose from (Table 1).

Table 1. Louisville project phase I multiple-choice question

What one issue are you most passionate about?	
1.	Income inequality
2.	College tuition and student debt
3.	Money in politics, gerrymandering, and election reform
4.	Public education
5.	Criminal justice reform
6.	Healthcare and health insurance
7.	Housing
8.	Social justice, racism, and LGBTQ rights
9.	Gun rights and regulations
10.	Drug legalization and the opioid epidemic
11.	Abortion and women’s rights
12.	Military spending, wars, and foreign aid

The methodology for collecting the actual samples from respondents involved directly engaging with the public. A population density map (Figure 2) was utilized along with a traffic density map (Figure 3) to collect a stratified sample that most accurately measured the population. Yamane’s formula was utilized to determine the optimal sample size required as nothing was known nor assumed to be known of the population or its mean prior to the collection of the sample (Adam 2020). A 95% confidence interval and P-value of .05 were also chosen. The population size was retrieved from the most recent census data from the time the survey was conducted, giving a required sample size of 400 (Note 4). Based upon this sample size requirement, 16 locations were selected with an intent to collect 25 samples from each location. The 16 locations were selected to accurately represent the spread of the population density of the city to ensure that there were no areas of higher density that would be underrepresented by the total sample collected. Furthermore, the exact locations chosen referenced traffic density near street intersections with traffic lights that would periodically stop traffic (Note 5). Saturdays and Sundays were specifically chosen due to higher levels of traffic on those days as observed in person. The measurements were also taken during midday which represented the highest conditions of traffic density. The sign was held and presented to sitting traffic during stoplights giving the members of the vehicles an opportunity to respond should they voluntarily feel inclined to do so.

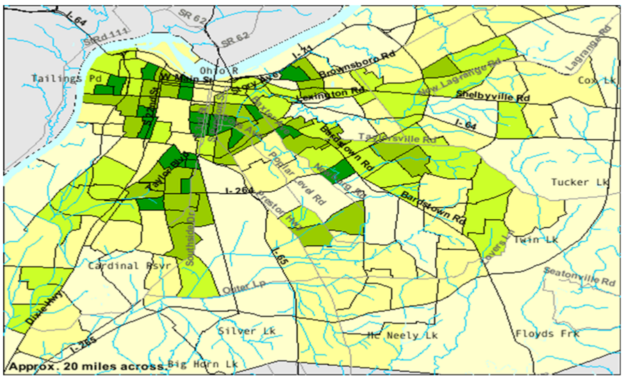

Figure 2. Thematic map showing population density of Jefferson County, Kentucky by census tract (Note 6)

Dark green represents a density of 7555 to 11225 persons per square mile. Pea green: 5164 to 7247. Bright green: 3326 to 5005. Yellow-beige: 1848 to 3240. Beige 115 to ~1800.

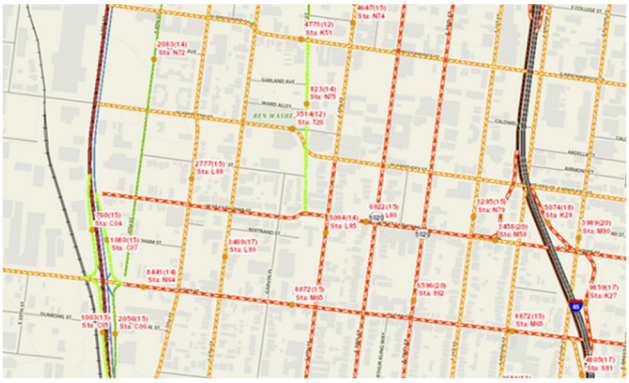

Figure 3. Traffic Density Map Example: Louisville Kentucky Example of traffic density (traffic counts) collected by the Kentucky Transportation Cabinet (Note 7)

It is important to protect each potential sample's choice to forgo a response. The voluntary nature of the sample collection methodology is intentionally designed to minimize bias. Protecting the voluntary nature of each individual response maximized the potential authenticity of each recorded response while minimizing any bias that may occur through forced or pressured response solicitation.

Respondents that did respond generally held up the number of their fingers aligned with the numerically labeled answer choice of their preference, or simply ignored the sign altogether. In cases where the same person expressed more than one answer, their answer tallies were not recorded. This choice was made to standardize accepted answers as one recorded response per one individual. The results from the phase one survey are presented in Figure 4. While a Pareto chart can be utilized in cases where more than one answer cumulatively represents the top 20% of the result, thus basing a phase two survey upon more than one result from a phase one survey, the decision was made in this case to continue to phase two with the most popular answer identified as "public education" for the sake of expediency and to align with the exploratory nature of the study.

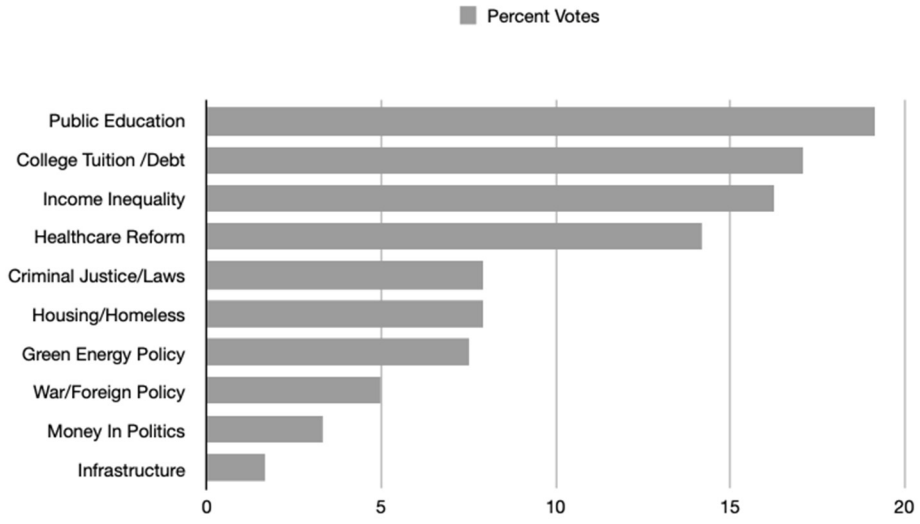

Figure 4: Louisville project phase I results

A new multiple-choice survey was created specific to public education (Table 2). An email listing of public-school teachers in the Louisville area was also collected. In this case, public school teachers were chosen

as an ideal sample target based upon their individual exposure to the full operational breadth of public education, including concerns experienced by students, parents, higher level administrators and their decision-making, and their own experience as teachers. The answer choices were created by researching current prominent issues within the realm of public education as well as corresponding with teachers and researchers working within the public education field. The survey was created in a digital format so that it could be offered via email to a sample of public-school teachers in the Louisville area.

Table 2. Louisville project phase two multiple-choice question

Unfunded Public Education Research Request	
Which item is the most important issue in the Jefferson County Public School system?	
a.	Student physical/mental health
b.	Technology/education innovation
c.	Funding/class size
d.	Teacher pay/tenure/support
e.	Student transportation
f.	Charter schools/vouchers/privatization
g.	Standardized testing
h.	Letter grades/4.0 grading scale
i.	School discipline/safety reform
j.	Parent/teacher/student/community engagement
k.	Other:

5. Results and Conclusions from the Exploratory Analysis

Due to an inability to gain permission from the Jefferson County Public School system's central office, phase two of the exploratory analysis was not completed (Note 8). The central office is the authority for the public schooling system in the city of Louisville, KY. A potential constraint exists in the implementation of TOCLSS/CI upon a geographical area that involves the requirement of top-down permission, or the pre-approval/authorization from any centralized organizational authority where samples are sought for collection. Even in cases where permission is granted from such centralized authorities, it remains possible that such permission would not necessarily elicit engagement by the members that authority represents. It could be the case that without further communicational support, a lack of trust may be encountered from the target population to be sampled, which can reduce or limit the response rate, potentially jeopardizing the targeted confidence interval or associated p-value.

Therefore, it may be beneficial to have an adequate communication plan developed and agreed upon whereby any centralized controlling authority exists within a targeted organization from whom samples are to be collected. The voluntary nature of the survey should always be protected and fully incorporated into the communication plan. The primary purpose in doing this is to minimize bias.

The geographical exploratory analysis conducted in Louisville, KY, did achieve several positive takeaways. It offers a clear example of what a transfer from one phase of sample collection to another looks like, as well as how the target population changes along with the survey itself. In this example, it shows how the planned medium of delivery of a survey can change from a physical sign to a digital electronic mail link. Most importantly, this exploratory analysis shows what the initial steps of primary constraint identification inside a TOCLSS/CI methodology looks like, and how it can be applied not only to organizations themselves, but to broader geographical areas as well. While the initial phase of the survey could be engineered to further reduce

bias, the results from the methodology implemented appear to show that the measurement taken in phase one can be viewed as a success.

6. Consideration Regarding the Voice of the Customer (VOC) Within Sample Collection

The Voice of the Customer (VOC) is an important perspective that should be considered when assisting organizations in optimizing the identification of primary constraints. VOC is a term referencing the collection of existing and potential customers' perceptions, perspectives, wants, needs, and requirements (Griffin and Hauser 1991). While there are several methods for acquiring an organization's VOC (Pyzdek and Keller 2014), two methods appear to prevent or minimize bias that can be easily applied or adapted when utilizing TOCLSS/CI. One method involves explicitly targeting or separating samples taken from the members of the organization whose time and exposure are more immersed in the customer experience. In essence, this sample would measure the collective insight of those who are most in touch with customer experience, especially including those who experience customer interactions on a daily basis. Another method for acquiring VOC while minimizing bias would involve a similar one-question survey. Fehlmann and Kranich found success in conducting such a survey, with their specific strategy relying heavily upon a secondary open-ended response asking customers to voluntarily explain their initial response (2012). Their study involved a question that asked each sampled customer how likely they would be to recommend a specifically identified organization to a family member or friend on a scale from 1 to 10. This was immediately followed by an open-ended and optional question allowing each customer the freedom and the opportunity to give a "why response" to the answer they provided for the original question. This "why response" became Fehlmann and Kranich's primary source of data to be analyzed. They then proceeded to categorize the why responses, and then quantify the categories to comparatively rank those customers' primary concerns. A potential drawback of this technique could involve a lower response rate due to an increased voluntary effort that must be applied by the customer to respond. It may also be the case that a customer may not be fully prepared for the question and have not taken adequate time to consider all possible answers.

The voluntary, single multiple-choice survey sampling method introduced in this paper could also be utilized specifically to target customer experience. The choices selected for customers within such single, multiple-choice questions can be created from an equal division of the whole of all possible customer experience categories. This single, multiple-choice question maintains an advantage over Fehlmann and Kranich's approach in that it more substantially maximizes buy-in by increasing the overall response rate through reducing the effort required to respond, further minimizing bias in the process. A further necessary process when utilizing this method will involve how and by whom or through which vehicle to deliver this single question to each individual customer.

Some variation of cost-benefit analysis should be considered depending on the type of organization and whether sampling customer-facing members of the organization will be accepted as measuring VOC, or if a separate and unique multiple-choice survey should be created and delivered directly to the customers themselves. If two separate surveys are utilized, one for internal members of an organization and one for the customers of that organization, there should also be a consideration and/or plan for how the results of the two surveys will be combined in the post-survey analysis. All of this should be incorporated into the cost-benefit analysis as to which technique is to be chosen to ensure that the VOC is not lost or overlooked.

7. Conclusions and Key Recommendations for Further Research

This paper sought to embed the emerging science of CI more fully within the field of operations management specific to continuous improvement and to the combination of Theory of Constraints and Lean Six Sigma (TOCLSS). Further research is needed to test the actual and potential efficacy of TOCLSS/CI in practice. An area of research utilizing this specific methodology should consider scalability. In theory, TOCLSS/CI could be applied across organizational boundaries, e.g., across entire supply chains or encompassing entire industries. The exploratory analysis in this paper shows how the methodology can be applied to a geographical area, and utilizing a similar technique, it can be applied to more than one organization at a time by sampling them as if they acted as one unit or equivalent to one geographical area. This may be beneficial in discovering deeper underlying constraints that exist within greater supply chains that may not be as quickly realized or addressed without such methodology. The same can be said when applying TOCLSS/CI to multiple organizations within an industry. It should also be noted that utilizing TOCLSS/CI doesn't need to impede any current or existing continuous improvement system. In essence, TOCLSS/CI can operate quietly in the background, minimizing any burden that may be placed on any organization willing to adopt its use. Further research is needed to verify

results when utilizing TOCLSS/CI, as well as an exploration of the potential limits of this methodology when applied to geographical areas or more than one organization at a time.

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Notes

Note 1. An open-ended question, in contradistinction to asking a simple multiple-choice question, would require additional categorization of the results and additional time, energy, and thought on behalf of respondents.

Note 2. Six Sigma includes methodologies directed towards the creation of new products, processes or services and identifies this methodology as Design for Six Sigma (DFSS) (Shahin 2008).

Note 3. Especially when, as is often the case, change management becomes central to proper solution implementation (Parker, Charlton, Ribeiro & Pathak 2013).

Note 4. Date of most recent census at time of survey was April 1, 2010. https://www.census.gov/quickfacts/louisvillejeffersoncountybalancekentucky

Note 5. Selected locations were visited in person in order to assess the feasibility of the location and adjusted based upon that observation.

Note 6. Kentucky Census Tract. https://www.commerce.gov/data-and-reports/population-statistics

Note 7. Kentucky Transportation Cabinet. Traffic Density Map. https://maps.kytc.ky.gov/trafficcounts/

Note 8. Jefferson County Public Schools (JCPS), Louisville, KY. https://www.jefferson.kyschools.us