Measuring Information Changes at Handoff Points

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Timely and accurate information handoffs or handover points are very important to ensure process continuity. Handoff points have been identified as points in the communication chain where information is altered. Information loss or distortion can lead to undesired or even fatal consequences. Experts in high-profile industries, such as telecommunications, healthcare and construction where communication accuracy and continuity is critical have developed and studied different handoff methods. There are several studies comparing different handoff styles and recommending strategies to improve handoffs. However, a generalized framework to quantify information change is currently not present. In this paper, a keyword-based approach to quantify information change during handoffs is proposed. When information keywords are identified, it becomes easier to transfer and gauge information change at the handoff points. It was also observed that the amount of information altered is dependent on the number of individuals involved with the process, individuals' subject matter expertise and the complexity of the information transferred. Insights gained from this research can help design phase gates review information content retained in the system and identify potential failure points in the communication chain, subsequently improving the handoff efficiency.

Keywords
Handoff Points, Measuring Information Changes, Keyword-based Approach

1. Introduction

Handoffs can be defined as points in the process where the involved participants (humans or systems) exchange tangible/intangible artifacts. In medical terms, a handoff is described as "transfer of professional responsibility and accountability for some or all aspects of care for a patient, or group of patients, to another person or professional group on a temporary or permanent basis" [1]. [2] explains the dual nature of the handoff points. On one hand, handoff points serve as points where process errors can be fixed; on the other hand, they are viewed as the most vulnerable point in a process. We can gain or lose information in the handoff process. Subsequently, handoff points should be considered vital points to warrant smoother process continuity. Timely and accurate handoffs increase decision-making speeds and also help streamline information flow thereby reducing the completion time for a certain process.

Measuring information changes during handoffs between systems, especially in the telecommunications industry, has been addressed. Claude Shannon's seminal paper [3] is widely accredited for introducing an entirely new discipline known as Information Theory. This work allowed engineers, for the first time, to measure the elusive concept of information [4]. However, information theorists and communication engineers are more concerned with the ability to transfer messages of a particular structure, rather than the content of the message [5]. Even Shannon states that "the semantic aspects of communication are irrelevant to the engineering problem" [3]. This is appropriate for the telecommunications domain and the engineering problems encountered therein. However, in many instances, we are more concerned with the semantics (intent) and content of the messages being handed off. This is especially true when we are dealing with humans who communicate in natural language. In order to complete tasks, people need to communicate with other individual(s) or groups/teams performing a given set of tasks with specialized knowledge and expertise. They will be required to interact while handing off information at some point in time. If information, knowledge or responsibility is not transmitted correctly and in a timely manner, the outcome can be suboptimal or sometimes even fatal.

Currently, no generalized framework to measure the amount of information, in a semantic sense, altered (lost or gained) during handoffs exists. A keyword-based approach to measure information change during handoffs is proposed in this paper. Such a framework can prove to be very useful to ensure process continuity by moving to the right next state and avoiding an undesired state. Additionally, this framework can be used to understand the number of players that should be involved, design review or phase-gates to identify potential delay/failure points in the communication chain and subsequently improve the handoff efficiency.

The remainder of this paper is structured as follows: Relevant literature review on handoffs and information theory as its applicable to the proposed framework is presented in Section 2. Section 3 describes the framework adapted to measure information change. Factors altering information during handoffs are presented in Section 4, followed with conclusion and scope for future work in Section 5.

2. Literature Review

2.1 Importance of Handoff Analysis

Handoff points are already defined in Section 1. Mathematically [6] defines a handoff as any irreflexive transitional relation between two or more players involved with the process, and is written as:

$$(x,x) \in R \text{ for each } x \in T \qquad (1)$$

Where, R is the relation defined on object x belonging to a given set of entities T.

Based on the above definitions, the following characteristics of handoffs are evident

- Handoffs occur when more than one entity (humans and/or systems) is involved with the process. We can define transmitters and receivers in the process.
- Artifacts, tangible or intangible, are transferred between these entities. It should be noted that intangible artifact exchange, (i.e., information or responsibility), can take place in either a verbal or nonverbal manner.
- The handoff point could mark the end of one process and beginning of the ensuing process step.

The study and analysis of the handoff points is very critical, especially in the human-centric processes, which are dominated by information exchanges between various resources. Handoffs in human-centric processes are extremely susceptible to information alteration leading to undesired consequences. This is evident from the Willie King case: The doctor received faulty information and amputated the wrong leg [7]. However, it is not clear in this case where the information was lost/distorted or who was responsible for the error. In another instance, Robert Woods' (pseudonym) diagnosis for tuberculosis was drastically delayed due to poor continuity of information communication at several handoffs ultimately leading to the patient's death [8]. The Committee on Patients Safety and Quality Improvement cites communication breakdowns at the handoff points as the leading cause of deaths in U.S. hospitals [9].

Even in the manufacturing domain there exists a significant number of interdepartmental handoffs (e.g., R&D, engineering, quality, operations, etc.) and intradepartmental handoffs (e.g., team meetings, shift changes, etc.). Studies have shown that personnel from one department may spend a substantial amount of unproductive time understanding the nature of work performed by personnel from another department [10]. Though the outcomes of tardy handoffs in manufacturing may not be as dramatic as those in the healthcare domain, delays and incorrect information handoffs can still prove to be expensive for companies.

In the construction industry, methodologies and tools are defined to guide the developers so that they avoid the pitfalls commonly seen during handoffs [11]. These guidelines are designed to increase speeds in decision-making, streamline information flow by reducing the process time-to-complete and to reduce material waste in construction activities.

Several studies have discussed different handoff styles and have recommended strategies to improve handoff efficiencies. [12] compared the verbal-only handoff method to both the verbal and note-taking method and the checklist handoff method. This study showed that the verbal-only handoff method was the least effective and resulted in the most loss of information in just five handover cycles, whereas the checklist handoff method was the most effective, and almost no information was lost. [13] recommended preventing interruptions and distractions during handoffs. [14] propose using unambiguous and standardized reporting style among units, shifts or teams and employing technology to improve handoff efficiencies. It was also recommended to employ skilled practitioners, well-versed in the art of interpretation, to manage communication handoffs [15].

The literature reviewed thus far did not provide any methods that could be employed to measure information changes during handoffs. Studies that highlight the importance of improving handoff styles and using skilled interpreters do exist. However, these studies do not provide any indicators that can help identify locations in the communication chain that need focus.

2.2 Overview of Information Theory

Though information technologies have been around since the first messages were recorded, it was not until the 20th century that engineers and scientists were able to qualify and quantify the term information [5]. Claude Shannon is widely credited with the creation of Information Theory. In fact, before Shannon introduced this theory, there were already attempts to define information in the context of communications process. The very first attempts to quantify information content are credited to Ralph V. L. Hartley. It was in the paper "Transmission of Information," [16] that Hartley recognized that information is obtained (with respect to telecommunications) when a symbol possessing the right value from a set of other possible values is received. In other words, reduction in uncertainty helps gain information. This is termed as uncertainty-based information [17].

Hartley showed that the only meaningful way to measure the amount of information was by using the following functional form [17]:

$$c \log_b \sum_{x \in X} r_{E(x)} \qquad (2)$$

Where, b and c are positive constants, and b ≠ 1. X is a finite set of mutually exclusive alternatives and E (evidence) is the set that some alternatives in X are possible($E \subseteq X$). Subsequently, r_E becomes the basic possibility function. Alternatively, Eq. (2) can be written as:

$$c \log_b |E| \qquad (3)$$

When $|E| = 2$, and $c \log_b |E| = 1$, unit of uncertainty measured is bits [17]. 1 bit measures uncertainty regarding the truth or falsity of one elementary proposition. This helps establish the Hartley measure H, which can be obtained by selecting b = 2 and c = 1 in Eq. (3). Subsequently, the Hartley measure can be written as:

$$H(r_E) = \log_2 |E| \qquad (4)$$

It can be seen from Eq. (4) that the Hartley function only depends on the number of elements in the set E and hence can be viewed as a function on natural numbers. This Hartley measure of a single event plays a fundamental role. It can be interpreted either as a measure of how unexpected the event is or as a measure of the information yielded by the event. It should be noted that Hartley's measure of information is a possibility function that ignores the probabilities of the various values of X. Though on the surface Hartley's measures seem independent of the probabilistic assumptions, some argue that this measure implicitly assumes that all alternatives follow a uniform distribution (i.e., they are equally weighted) [18].

This particular shortcoming is addressed by Shannon. He was the first to address the means of measuring amount of uncertainty in classical probability theory. [17] states that the only meaningful way to measure the amount of uncertainty expressed by probabilistic distributions (of function p, for example) on a finite set can be expressed in the form of Shannon's entropy:

$$-c\sum p(x)\log_b p(x) \tag{5}$$

Where, similar to Eq. (2), b and c are positive constants, and $b \neq 1$. Based on Eq. (2) and Eq. (5), it is not difficult to see that the Hartley measure and Shannon's entropy are related. Shannon's measure of information (entropy) coincides with Hartley's measure when and only when the possible values of X are all equally likely. Shannon's entropy, in a sense, is the average Hartley measure [4].

The intent of this paper is not to compare and contrast these two theories. It should suffice to say that the Hartley measure is based on the possibility approach, whereas Shannon's entropy is probabilistic in nature. Interested readers are recommended to refer [3–5, 16–18] for more information.

However, uncertainty-based information, by nature, is restricted. Information measured by reduction of uncertainty, (i.e., uncertainty-based information) does not capture "common-sense conception of information in human communications…" [17]. Though these theories are in their embryonic stages to be used for human communications, an attempt has been made in this paper to lay the application foundations.

3. Measuring Information Change

Since the methodology uses a keywords-based approach, it is important to define keywords in this context. Keywords can be defined as a set of critical artifacts or packets - tangible or intangible. Handoffs in human-centric processes typically occur among human-to-human, system-to-human and human-to-system. These interactions are dominated by exchanging/handing off information or decision packets [19]. Thus, in the context of human-centric processes, keywords can be considered to be information packets that include, but are not restricted to, written or spoken language, text, signs, symbols, numerical information or a combination of all.

For simplicity, consider a communication chain comprising of two sets A and B which can represent an individual, team or system(s). A and B are related (connected) to each other as shown in Figure 1. This can be represented mathematically as $(A,B)\in R$. In this case R can be thought as a successor relationship.

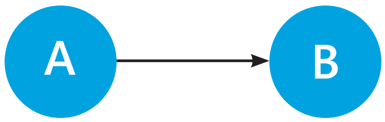

Figure 1: Relationship between Sets A and B

Based on the mathematical definition of a handoff, as presented in Eq. (1), the aforementioned relationship clearly demonstrates a handoff point between A and B. It can be assumed that at this juncture that some information packets will be exchanged. In Figure 1, A can be considered as the source or transmitter and B as the receiver.

Let $X = \{w_1, w_2, \ldots, w_n\}$ be a finite set of mutually exclusive keywords, containing all the necessary information packets we need to handoff. Let us assume that the source has all the necessary information and is able to transmit all of it to the receiver. Thus, we are limiting any loss of information during information transmission from the source, (i.e., there is no information loss at A. Subsequently, we now will have information loss at the receiver's (B's) end. This loss could be attributed to B's capability to understand/interpret information. In this case we can say that *B* receives *K* set of keywords. Thus $K \subseteq X$; and $K=\{w_1, w_2, \ldots, w_m\}$, where $m \leq n$. Though, K can be thought as synonymous to E (evidence), to the contrary, in our context K is defined on X as the subset of critical keywords lost during the transmission process.

Since X is a finite set of keywords, this set can further be treated as discrete number of information packets. Hence, we can say that B either receives a given information packet or does not. Subsequently, we state that the possibility function as, $r_K \in (0,1)$; 0 when information packet is received, 1 when information packet is not received. Given this argument and mathematical form, we can see that Hartley's information measure can be adopted. Thus we can formalize the amount of information loss at handoff (U_K) similar to that given in Eq. 2. In this case, we too will use b = 2, to measure information loss in bits. Bits is an appropriate unit of measure in our case as 1 bit can be used to measure the information content regarding the truth (information packet received) or falsity (information packet not received).

When all information packets are received by B, the information loss is 0. On the other hand, a complete state of ignorance occurs when none of the information packets are received i.e., when K = X. This complete state of ignorance will be a function of number of information packets transmitted from the source and can be represented as $\log_2|X|$. The total amount of information (U_K) contained at the end of the handoff process will be:

$$0 \leq U_K \leq \log_2|X| \qquad (6)$$

Now consider a larger chain with multiple participants (individuals or teams), wherein information flows in a sequential/hierarchical order, (e.g. – from the manager, to the engineer, and to the line operator). For such a sequential process, it is easy to identify the source of this information flow. In real-world instances, we may come across situations with multiple sources—participant receiving/sending information to one or more participant and may not necessarily be a hierarchical communication chain. However, even in these instances Eq. (6) holds good.

To illustrate this proposed methodology, a handoff scenario was simulated. A group of seven participants, including the source (selected randomly), were selected. To remove any understanding bias, participants with similar educational and professional backgrounds were chosen. A process known best to the source was selected, and 20 keywords relevant to various process steps were identified. Each chosen keyword was thought to be equally important from the process viewpoint and thus equally weighted.

The source (Participant 1) conveyed all the information verbally to the first receiver (again randomly selected), this participant to the next (and so on) until the last participant reiterated the process. As long as the participant conveyed the meaning (essence) of the keyword, it was considered a successful handoff. However, if the participant failed to do so, it was considered as a miss, (i.e., lost information packet) and was recorded (marked 1). In a similar manner, all such lost information packets (keywords) were recorded at each handoff point. The handoff points were uniformly spaced over a timeframe of one hour, (i.e., each participant handed information over to the next participant after one hour). The results for this experiment are summarized in Table 1.

Table 1: Experimental Results Recording Number of Lost Information Packets (Keywords)

Keyword	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7
1						1	1
2			1	1	1	1	1
3							
4		1	1	1	1	1	1
5							
6							
7							1
8							
9				1	1	1	1
10					1	1	1
11					1	1	1
12		1	1	1	1	1	1
13							
14			1	1	1	1	1
15		1	1	1	1	1	1
16			1	1	1	1	1
17			1	1	1	1	1
18							
19		1	1	1	1	1	1
20							
Total Misses	**0**	**4**	**8**	**9**	**12**	**13**	**14**

It was observed that Participant 2 failed to receive (failed to understand and reiterate the process) 4 of the 20 keywords, i.e., K = 4. Thus, the amount of information lost by Participant 2 can be written as $U_K = \log_2|4| = 2$ bits. Hence, it can be inferred that 2 bits of information was lost at the handoff between Participants 1 and 2. The total amount of information lost for the entire chain can be calculated as $U_K = \log_2|14| = 3.81$ bits. The total state of ignorance would have occurred if we were to lose all the keywords (information packets), viz. $\log_2|20| = 4.32$ bits. However, one can argue that the remaining information may not really help either.

For this experiment, Participants 2 and 3 lost the most amount of information in this communication chain. In both cases, the amount of information lost by these participants was 2 bits. Thus, we see how this approach also helps identify and quantify information loss at a certain stage by specific participant. Such indicators can be used to design phase gates or checkpoints to avoid distorted information from continuing downstream of the communication chain. Feedback loops could also be designed when participants may have a high likelihood of losing information, or these participants can be paired with more experienced/skilled individuals to avoid information loss.

4. Reasons for Information Distortion at Handoff Points

As previously mentioned, the amount of information received can be a function of the receiver's capabilities to understand or interpret it. This clearly demonstrates a need for transmitting information in a form that is familiar to the receiver or pairing the receiver with a subject matter expert. However, the complexity of information being handed over and the number of handoffs (i.e., number of participants involved in the communication chain) influence the amount of information retained in the system. To confirm these hypotheses, a 2^k factorial design with three replicates was created. The factors and their corresponding levels are shown in Table 2.

Table 2: Factors and Levels Influencing the % Information Retained

Factors	Levels	Specifications
Information Complexity	Low (-)	10 Keywords
	High (+)	20 Keywords
Number of Participants	Low (-)	3 Participants
	High (+)	7 Participants

The normal probability plot of the standardized effects with a confidence level of 95% is shown in Figure 2. This plot highlights the significant factors influencing the response (information retained). ANOVA results (Table 3) and the normality plot indicate that both the factors, information complexity and number of participants, have a significant impact on the response.

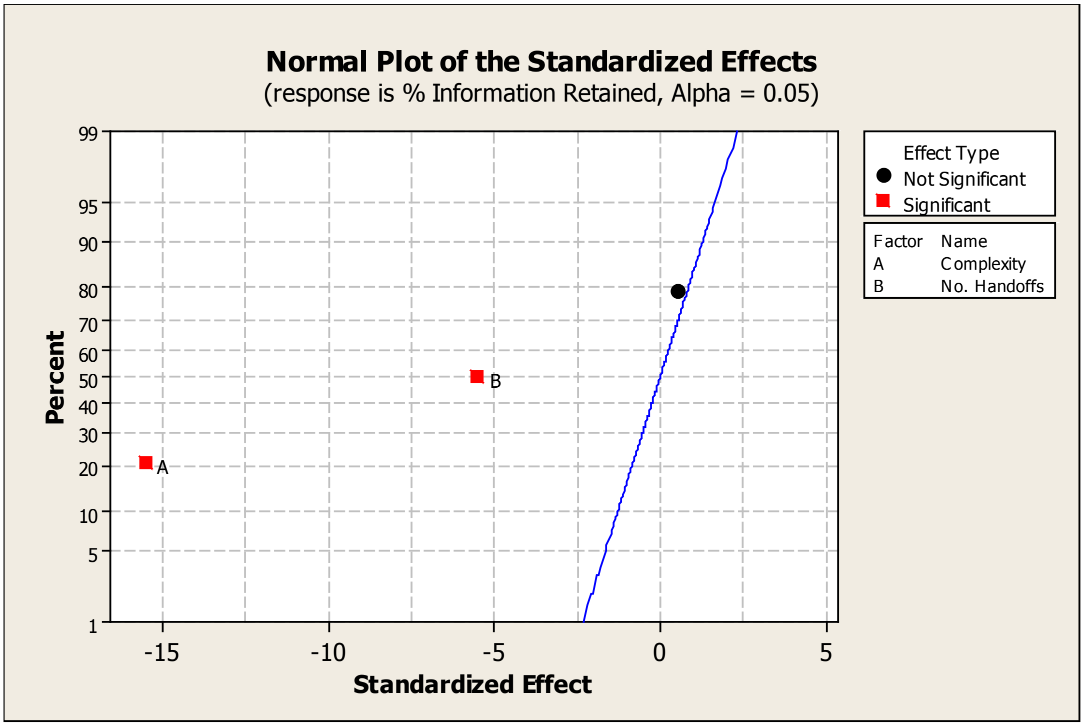

Figure 2: Normal Probability Plot of the Standardized Effects

Table 3: ANOVA Results

Source	DF	SeqSS	Adj SS	Adj MS`	F	P
Main Effects	2	9016.67	9016.67	4508.33	135.25	0.000
Residual Error	8	266.67	266.67			
Total	11	9291.67				

It was also seen that the two factors are linearly dependent on each other (i.e., when the information complexity and the number of participants increase (decrease) the amount of information retained in the system decreases (increases)). These results support the hypothesis that increased complexity and people involvement decreases the amount of information retained in the system.

Since handoff points are associated with holdups and delays, a fewer number of handoff points are desired [20]. Additionally, it can be said that an increased number of handoffs can increase the probability of information distortion. Thus, fewer numbers of handoffs are not only required to reduce holdups and delays but are also essential to avoid undesired consequences.

5. Conclusions and Future Work

Accurate information transmission is important to maintain process continuity and avoid delays or other undesired consequences. Several examples are cited in literature describing the importance of timely and correct handoffs. A generalized framework to measure the amount of information lost in communication chains was presented in this paper. The proposed method uses a keywords-based approach where keywords can represent tangible or intangible artifacts/packets. This method assumes a possibilistic view and uses Hartley's measure wherein information loss in the communication chain is calculated in bits.

A simple communication chain with multiple handoff points was simulated to demonstrate how the proposed method can be applied. Identifying and quantifying information losses help detect points in the chain (participants) where most of the information was lost. These points can be considered as susceptible points in the communication chain. Subsequently, appropriate measures can be put in place if we can identify these points in advance. Additionally, it was observed that the amount of information retained in the system is highly dependent on the complexity of information, number of participants and number of handoff points involved in the communication chain. Greater complexity and a larger number of handoffs decrease the amount of information retained in the system. This conclusion also supports the lean philosophy that a higher number of handoffs would increase the time delays, and a lower number of handoffs are preferred.

This research provides motivation for conducting further studies using concepts from human factors in engineering, psychology, organizational behavior and sociology to examine training needs/effectiveness and identify means to develop better communication protocols, etc. Studies focusing on human behavior, employee motivation, group dynamics, memory retention, self-efficacy and similar attributes to improve the overall efficiency of the system can also be developed and applied to appropriate locations in the communication chain.

It should be noted that this study is in its infancy stages. It helps lay the foundation for more in-depth analysis to quantify information losses at handoff points. In the proposed method, certain assumptions were made, (e.g. source transmits all the necessary information in the right fashion; information is not lost during transmission from transmitter to receiver, (i.e., the arrow (→) connecting A and B in Figure 1), information receipt is considered possibilistic in nature, (i.e., B either receives the information or does not), all keywords are assumed to be mutually exclusive alternatives and thus are equally weighted and a keyword once lost in the communication chain is lost forever, etc. These assumptions may not necessarily hold true in real-life cases. To avoid these shortcomings and to invoke probabilistic assumptions, attempts should be made to see how Shannon's entropy measures can be applied. Additionally, to relax the assumption that keywords are mutually exclusive, conditional probabilities can also be applied within Shannon's measure.

However, even applying Shannon's measures may not be adequate to completely model the dynamic nature of human communications systems. By dynamic nature refers to two main components: time and direction. For evolving and dynamic systems, a researcher can incorporate transient probabilities (modeled as Markov chains) as opposed to static probabilities, which are used in Shannon's measures.

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