Framework for Knowledge Management

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Abstract

This thesis studies the underlying processes of Knowledge Management (KM) and proposes a generic framework for knowledge management that is applicable to real-life case studies.

We define KM as gathering, refining, organising and disseminating knowledge in an organisation, modelled as a multi-agent system.

We identify the processes that support KM in such a system. We then formalise the processes using the syntax and semantics of epistemic logic and translate multi-agent dialogues into a protocol language, which is verifiable by model checking in SPIN. We investigate two real life case studies, knowledge sharing and knowledge gap and verify the underlying processes. We finally check for correctness properties of the knowledge processes, including absence of deadlock and termination.

Dedication

I would like to dedicate this thesis to my parents Razia Sultana and Mohammad Hussain and in memory of my grand parents.

Acknowledgements

First of all, I would like to thank my supervisors, Professor Rob Pooley and Dr. Lila Georgieva for their consistent guidance throughout my studies at Heriot - Watt University.

Declaration

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Publications

Parts of the thesis have already been published and presented at the following peer-reviewed events:

CIKM 10th European Conference on Knowledge Management, University of Padua, Vicenza, Italy. Title: "Simulation of Knowledge Management Processes in Multi-Agent Systems", the work submitted at this conference can be found in chapter 5 [37], which explains different models of knowledge management, and proposed framework of selected streams and the language used for formalisation. A journal version of [37] is currently under review.

MKM Third KES International Symposium, KES-AMSTA 2009, Uppsala, Sweden, June 2009. Title: "Knowledge Management in the Digital Economy". The work submitted at this conference can be found in chapter 2, which involves using the SPIN tool for model checking and verifying the processes of knowledge gap shown in chapter 7 and knowledge-sharing protocol shown also in chapter 7 [35].

Lifting the Lid University of Edinburgh School of Informatics Forum, 19 November 2008. The School of Informatics presents *Lifting the Lid*, a technology showcase for Scottish informatics research of interest to SMEs as well as to larger organisations. The information displayed on the poster contains information on knowledge instruments found in chapter 2 and knowledge streams in chapter 6 [36].

Chapter 1

Introduction

This thesis gives an insight into Knowledge Management (KM) initiatives that are being implemented by organisations and analyses the static models of KM used. We propose a general framework for modelling knowledge throughout an organisation, using processes and protocols susceptible to verification and simulation.

Our KM framework will be applied to specifically selected real life case studies from various industries and identify important knowledge processes also known as knowledge streams for the selected case studies we then identify the knowledge processes involved by using our knowledge management framework.

We will now compare the definitions of knowledge management presented by various authors.

It is crucial for organisations to understand what knowledge management is and what impact it has on the organisation. Many of the small organisations are not ware of the term knowledge management and what benefits can be derived from this discipline the knowledge management assists to promote to identifying capturing, evaluating and sharing of a companies information assets these can include databases, policies, documents and KM systems. The normal management process in smaller and larger organisations entail conducting meetings between departments, attending seminars, brain storming sessions to solve problems, acquiring knowledge databases depending on the nature of the business. The normal knowledge process is categorised as collecting information,storing information, making the information available and use the information.

Kuwan and Aspinwall [51] states that knowledge is data organised into meaningful patterns and that information is transformed into knowledge when a person reads and understands it and applies it. KM is concerned with the capture, organising, sharing and storage of the knowledge experiences of individual workers and groups within an organisation. KM is a cornerstone for companies in developing a sustainable competitive advantage and in remaining at the forefront of excellence in a level-playing field market Nonaka and Teece [67]. KM, if properly harnessed, can propel organisations into becoming more adaptive, innovative, intelligent and sustainable Lim and Klobas [54]. Small Medium Enterprises (SMEs) and large organisations should have the ability to capture and share knowledge and to know, how it is transferred within the company. Using knowledge is a key determinant and predictor of value, therefore it has become necessary for practitioners, managers, academics and researchers to address its management Kuwan and

Aspinwall [51], Lim and Klobas [54] and Tobin [89].

It is stated by [89] that KM does not need a large IT system: it's a matter of organising knowledge and incorporating it into the culture, and finding out what employees know and how the knowledge can be beneficial to the organisation. Our current work contributes towards building a framework for organisations that does not require large IT systems or large expense. The proposed framework lets organisations discover the knowledge residing within company and the flow of knowledge throughout, by using a branch of modal logic called epistemic logic. This is a language used to formalise complicated scenarios. It is crucial for organisations to understand how to utilise their resources effectively, which in return can assist in sharing the knowledge throughout the organisation. Valuable human knowledge resources will be wasted unless management openly accepts and supports efforts to gather, sort, transform, record and share knowledge Nonaka and Teece [67]. Owners of small companies tend to focus on the core of their business and pay less attention to other important issues, such as KM. It is argued by Kuwan and Aspinwall [51] that smaller organisations cannot afford to pay attention to the KM aspect of the business, or that businesses do not want to commit to the expensive consultancy services used by larger firms.

When an organisation uses KM, the employees are able to use the knowledge database to familiarise themselves with knowledge such as training articles and problem-solving techniques.

Nonaka [67] extends the description by stating that knowledge management can be used as a learning tool in any organisation and as an objective.

We extend our KM framework by verifying agent processes in dialogue scene where we can identify what knowledge is in the organisation.

We have briefly discussed various definitions of KM and gave an introduction of our KM framework. In the next section, we present the structure of the thesis.

1.1 Structure of the Thesis

The thesis has eight chapters. Chapter 1 is the introduction, and gives the aims and objectives. Chapter 2 introduces the basic language and tools used for formalisation and verification. Chapter 3 discusses the motivation of the thesis and Chapter 4 discusses the background. Chapter 5 compares the differences between formal models of KM and computational models. Chapter 6 discusses the proposed framework and the KM streams involved. Chapter 7 applies the framework to selected real-life case studies. In chapter 8 we discuss the Evaluation from the questionnaires. In Chapter 9 we discuss the future of KM and give the conclusions.

The next section gives the aims and objectives for this research.

1.2 Aims and Objectives

The aims of this thesis are to:

- Review approaches to KM and formal models of KM.

- Analyse how SMEs and large organisations can identify knowledge in their companies.
- Conduct questionnaires from organisations and analyse results.
- Propose and Develop a formal framework for KM in organisations.
- Check knowledge properties using SPIN model checker.

1.2.1 Contribution

The basic objective of the thesis is to put forward ideas and concepts on knowledge management and the modelling of multi-agents. It proposes a simulation of agent communication and verification of KM processes. SPIN checks the processes for safety, termination, deadlocks and liveliness. Other KM models presented in the research involve static KM models in comparison to the one we propose. The knowledge process in the proposed framework allows analysis of the movement of knowledge in SMEs and large organisations.

At this stage we, have discussed the objectives of the thesis and the structure and what our contributions are. In the next chapter, we discuss the basic concepts which deal with the languages for formalisation.

Chapter 2

Basic Concepts

In this chapter, we discuss the languages used for formalisation and their syntax and semantics. We use basic verification tools in our research to formalise and verify the knowledge processes which are created. Logics is one of the fundamental aspects of knowledge representation and developed as an attempt to create a universal language based on mathematical principles Blackburn et al [76]. The vocabulary used is a collection of symbols represented as characters. Semantics deals with theory of reference that determines how constants and variables relate to objects in the universe of discourse. This also includes a theory of truth to distinguish the statements from false Blackburn et al [76].

In the next section we discuss the Logical concepts used.

2.1 Logical Concepts

In this section we will introduce a collection of inference rules that will provide the basis for reasoning rigorously about access control. The rules provide a description of a system for manipulating well formed formulas as a way of calculating the consequences of various assumptions.

We will demonstrate how we can relate the rules of inference with our knowledge sharing case study which uses similar concepts and show the tautologies and various inference rules then give a description of them at a later stage in this section. Informally we often read the following rules as "if all the assertions on the top are true, then the consequence below the line will also be true." The logical rules describe a system for manipulating well- formed formulas of the logic

We now list briefly the logical rules for access control logic which are listed below then we will go through each one and explain different rules and how they relate to our research. We will be using the agent i and agent j and introducing two statements α and β.

The below statement signifies a tautology if α is an instance of a propositional logic tautology:

Taut $\dfrac{}{\alpha}$

Modus Ponens $\dfrac{\alpha \qquad \alpha \Rightarrow \beta}{\beta}$

The above translates as:

Knows $\dfrac{\alpha}{\alpha\ knows\ \beta}$

Then MP knows translates as $\overline{(i\ knows(\alpha \rightarrow \beta)) \rightarrow (i\ knows\ \alpha\ \ \rightarrow i\ knows\ \beta)}$

Knows for translates as: $\overline{(\alpha \rightarrow \beta \rightarrow (\ i\ knows\ \alpha \rightarrow j\ knows\ \alpha)}$

and knows translated as $\dfrac{\alpha}{\alpha\ knows\ \beta}$

stating: $\overline{(i \mid j\ knows\alpha) \leftrightarrow (i\ knows\ j\ knows\ \alpha}$

Idempotency of $\rightarrow$ $\overline{i \rightarrow i}$

Transitivity of $\rightarrow$

$$\frac{i \rightarrow j \qquad j \rightarrow r}{i \rightarrow r}$$

Monotonicity of $\rightarrow$ $\dfrac{i \rightarrow i' \qquad j \rightarrow j}{i \mid j \rightarrow i' \mid j'}$

Common propositional logic tautologies are listed below, these can be translated as following: p implies a proposition statement and q implies a propositional statement e.g. if we relate this to the case study we can have the following translation p and q $p =$ statement data sheets and q statement implies customer complaint forms. We show below the axioms that state any instance of tautology from the propositional logic can be introduced at any time as a derivable statement. To make it clearer what the rules mean propositional logic tautology which is a formula that evaluates to true under all possible interpretations of its propositional variables. If we look at the formula $p \vee \neg p$ always evaluates to true, independent of whether the propositional variable is p is assigned to true or the value false. In contrast the formula $p \rightarrow \neg p$ is not a tautology, because it evaluates to false whenever p is assigned to true.

Table 2.1: Common Propositional - Logic Tautologies

$p \vee \neg p$	$p \rightarrow (q \rightarrow (p \vee q))$
$p \leftrightarrow (\neg \neg p)$	$(p \wedge q) \rightarrow (p \rightarrow q)$
$p \rightarrow (q \vee p)$	$(p \wedge q) \rightarrow (q \wedge p)$
$p \rightarrow (q \rightarrow p)$	$(p \leftrightarrow q) \rightarrow (p \rightarrow q)$
$(p \wedge q) \rightarrow p$	$((p \vee q) \wedge \neg p) \rightarrow q$
$\neg (\neg p \wedge p)$	$((p \rightarrow q) \wedge (q \rightarrow r)) \rightarrow (p \rightarrow r)$

The modus ponens rule which is a common rule used $\dfrac{\alpha \qquad \alpha \rightarrow \beta}{\beta}$

The rule above states that if both the implication $\alpha \rightarrow \beta$ and the formula β, if we relate this to the case study scenario we can derive the following:

agent i wants to share information with agent j

(agent i knows a fact) $\rightarrow$ sharing and agent i knows a fact

The knows rule:

The knows rule is defined as follows:

$$\frac{\alpha}{i\ knows\ \alpha}$$

This rule states any principal can make any statement (or safely been assumed to have made an statement) that has already been derived.

The MP Knows rule

The MP knows axiom serves as a version of modus ponens for statements made by principals:

MP Knows $\overline{(i\ knows\ (\alpha \to \beta)) \to (i\ knows\ \alpha \to i\ knows\ \beta)}$

in effect this rule allows us to distribute the knows operator over implication e.g. this axiom allows us to derive the following formula in relation to the knowledge sharing scenario:

lets say agent i represents an employee

(employee knows(customer survey forms → share)) →((employee knows customer survey forms) →(employees knows share))

The knows for rule:

The knows for axiom is defined as follows: Knows for $\overline{i \to j \to (i\ knows\ \alpha \to j\ knows\ \alpha)}$

The above formula captures our intuition about the knows for relation. It states that if i knows j then any statements i makes should also be attributed to j.

We can derive the following statement:

agent i $\rightarrow$ agent j ((i knows survey forms) $\rightarrow$ agent i knows survey forms))

we have derived the formula agent i $\rightarrow$ j the modus ponens rule would let us also derive the formula: (agent i knows survey forms) $\rightarrow$ (agent j knows survey forms).

We have two rules that relate statements made by compound principals to those made by simple principals. The first of these is the and knows rule.

and knows $\frac{}{(iandjknows\alpha) \leftrightarrow ((i\ knows\ \alpha \wedge (i\ knows\ j))}$

This rule reflects the conjunction nature of a principal i and j: the statements made by the compound principal i and j (e.g. i in conjunction with j) are precisely those statements that both i and j are willing to make individually e.g. the and knows rule allows us to derive the following formula:

(agent i and agent j knows survey forms) $\leftrightarrow$ ((agent i knows survey forms) $\wedge$(agent j knows survey forms)).

The second rule is the knowing rule

Knowing: $\frac{}{(i \mid j\ knows\ \alpha) \leftrightarrow ((i\ knows\ j\ knows\ \alpha)}$

The rule above captures the underlying intuition behind the compound principal i | j: The statements made by i | j (i.e. i knowing j) are precisely those statements that i claims j has made here this is an instance of the knowing rule giving an example from the case study:

(employee | team leader knows share with employees) $\leftrightarrow$ employee knows team leader knows to share with employees).

Properties if $\rightarrow$ have three rules that relate to properties of the $\rightarrow$ relation, namely ideopotency, transitivity and monotonicity. These rules are all quite simple but they are useful for analysing situations that involve chains of principals speaking for one another as we have previous mentioned at the beginning of the documents these can be put in context, we will give an example of each and relate them to the case study in the research showing its relevance first we will start of with:

Ideopotency:

The ideopotency rule of $\rightarrow$ states that every principal speaks for itself:

Ideopotency of $\rightarrow$ $\dfrac{}{i \rightarrow i}$

with the rules above we can derive the following formula agent i $\rightarrow$ i if we were to give an interpretation in relation to the case study we can say that employee named i implies that employees named i.

The rule above seems obvious and unnecessary, it can be useful in conjunction with monotonicity to reason about knowing principals:

The transitivity of $\rightarrow$ rule supports reasoning about chains of principals that represents one another:

Transitivity of $\rightarrow$ $\dfrac{i \rightarrow j \qquad j \rightarrow r}{i \rightarrow r}$

This rule states that if one principal knows for a second and the second also knows for the third then it is also safe to view the first principal as knowing for the third principal e.g. if we have previously derived the two formulas if we take the scenario from the case study where employees passes information to the team leader resulting in the team leader knowing the information as stated below:

employee → team leader team leader → information

then the transitivity of the → rule allows us to also derive

employee → information.

The last rule Monotonicity of → $\dfrac{i \to \beta' \quad j \to \alpha'}{i \mid j \to \alpha' \mid \beta'}$

As an example suppose that we have already derived the following formulas:

employee → information team leader → knowledge

the monotonicity of the → rule allows us to also derive the formula:

employee | team leader → information | knowledge.

If we were to see the utility of idempotency, we consider the case where we have already derived the formula employee → team leader and we would derive that:

employee | manager → team leader | manager.

By first using the idempotency to derive manager → manager we can use the monotonicity to derive the desired formula.

We will now look at the equivalence rule:

The equivalence rule allows one to replace sub formulas in a formula with equivalence

Equivalence Rule: $\dfrac{\phi 1 \leftrightarrow \phi 2 \quad \psi[\phi 1/q]}{\psi[\phi 2/q]}$

To understand this rule one must understand the meta - notation ψ [ϕ/q] which denotes the result of replacing every occurrence of the propositional variable q within the formula ψ by the formula ϕ e.g.

(t $\rightarrow$ (i knows (r $\wedge$ t)))[j knows s/t]

which is simplified as (j knows s) $\rightarrow$ $(jknows(r\wedge$ j knows s)) meaning that the equivalence rule states that, if formulas $\phi 1$ in a formula ψ [ϕ/q] can be replaced by $\phi 2$ resulting in the formula ψ [$\phi 2$/q] say for example we have already derived the following two formulas:

s $\wedge$t $\leftrightarrow$ agent i knows r, employee | team leader controls (s$\wedge$t)

the latter formula is equivalent to (employee | team leader controls [(s$\wedge$t)/p] because the rule allows us to derive the formula:

employee| team leader controls (agent i knows r).

by choosing ψ and the propositional variable q judiciously, one can also use the equivalence rule to replace only some of the occurrences of $\phi 1$ and $\phi 2$. As an example suppose that we have previously derived the following two formulas:

(t $\rightarrow$r) $\leftrightarrow$ i knows w ((R knows (t$\rightarrow$r)) $\wedge$ (t$\rightarrow$r)) $\rightarrow$(T|R controls(t$\rightarrow$r))

The latter formula can be obtained by any of the following substitutions (among others)

(((R knows (t $\rightarrow$)) $\wedge$ q) $\rightarrow$(T|R controls (t$\rightarrow$r)))[t$\rightarrow$r/q]

(((R knows (t $\rightarrow$)) $\wedge$ q) $\rightarrow$(T|R controls q))[t$\rightarrow$r/q]

(((R knows q) $\wedge$ q) $\rightarrow$(T|R controls q)) [t$\rightarrow$r/q]

(((R knows (t $\rightarrow$)) $\wedge$ q) $\rightarrow$(T|R controls (t$\rightarrow$r))) [P knows w/q]

(((R knows (t $\rightarrow$ r)) $\wedge$ q) $\rightarrow$(T|R controls q))[P knows w/q]

(((R knows q) $\wedge$ q) $\rightarrow$(T|R controls q)) [P knows w/q]

in the next section we give the definition that governs the use of controls in our logic:

i controls ψ def (i knows ψ) $\rightarrow \psi$

This definition states that a formula of the form i controls ψ is syntactic sugar for the longer expression (i knows ψ) $\rightarrow \psi$. That is the controls font give our logic any additional expressiveness, but it provides a useful way to make more explicit what will turn out to be a common idiom, this definition means that any time we see an expression of form i knows ψ we can replace it by (i knows ψ)$\rightarrow$ and vice versa.

As an example of the use of this definition we can replace any occurrence of the formula agent i controls read - even within the context of a larger formula.

A simple formal proof is given to demonstrate this:

Table 2.2: Simple Formal Proof

1. i knows (r$\rightarrow$s)	Assumption
2. r	Assumption
3. (i knows (r$\rightarrow$ s)) $\rightarrow$(i knows r $\rightarrow$ i knows s)	MP knows
4. i knows r $\rightarrow$ i knows s	1,3 Modus Ponens
5. i knows r	2, knows
6. i knows s	4,5 Modus Ponens

Formula (agent i controls read) $\rightarrow$ read and vice versa. Thus e,g, the controls definition allows us to replace the formula:

Table 2.3: A formula of the controls rule

1. i controls ψ	Assumption
2. i knows ψ	Assumption
3. (knows ψ) $\rightarrow \psi$	1. Defn controls
4. ψ	2,3 Modus Ponens

agent i knows (agent j controls read)

by the formulas:

agent i knows((agent j knows read)$\rightarrow$ read)

Formal Proofs and theorems: A formal proof is a sequence of statements of the logic where each statement is either an assumption or a statement that can be derived by applying one of the inference rules (or definitions) to previous statements in that sequence. It is customary to sequentially number each of these statements and to label them either with assumption or with the statement numbers and inference rule name by which it was deduced.

The table 1 "simple formal proof" in this case study only the first two statements in the proof are assumptions: every other statement is either an instance of axiom (step three or a consequence of applying one of the inference rules. As another simple example above for the formal proof controls demonstrates how the definition of the controls operator can be used to formal proof. Every formal proof gives a theorem, which is really just a derived inference rule specifically if the only assumption of the formal proof is statements.

The formal proofs in the above tables correspond respectively to the following two derived theorems:

Derived from table 1
$$\frac{agentiknows(t \rightarrow s)r}{agentiknowss}$$

Derived from table 2
$$\frac{i\ controls\ \psi i\ knows\ \psi}{\psi}$$

The theorem can be used as additional inference rules in any future proof without affecting that proof's validity. There are many derived rules some from propositional logic. For reference we have summarised the rules along with controls:

Derived rules: Conjunction $\frac{\phi 1 \phi 2}{\phi 1 \wedge \phi 2}$

Simplification 1 $\frac{\phi 1 \wedge \phi 2}{\phi 1}$

Simplification 2 $\frac{\phi 1 \wedge \phi 2}{\phi 2}$

Disjunction 1 $\frac{\phi 1}{\phi 1 \vee \phi 2}$

Disjunction 2 $\frac{\phi 2}{\phi 1 \vee \phi 2}$

Modus Tollens $\frac{\phi 1 \rightarrow \phi 2 \neg \phi 2}{\neg \phi 1}$

Double negation $\frac{\neg\neg\phi}{\phi}$

Disjunctive Syllogism $\frac{\phi 1 \vee \phi 2 \neg \phi 1}{\phi 2}$

Hypothetical Syllogism $\frac{\phi 1 \rightarrow \phi 2 \;\; \phi 2 \rightarrow \phi 3}{\phi 1 \rightarrow \phi 3}$

Controls: $\frac{P\ controls\ \phi P\ knows\ \phi}{\phi}$

Derived Knows for $\frac{P \rightarrow Q\ \ P\ knows\ \phi}{\neg \phi 1}$

Derived controls $\frac{P \rightarrow Q\ \ Qcontrols\ \phi}{P\ controls\ \phi}$

Knows Simplification 1 $\frac{Pknows(\phi 1 \wedge \phi 2)}{Pknows\phi 1}$

Knows Simplification 2 $\frac{P\ knows\ (\phi 1 \wedge \phi 2)}{P\ knows\ \phi 2}$

In the next section, we discuss modal logics and syntax and semantics.

2.2 Modal Logic – Syntax and Semantics

Modal logic extends classical logic with the ability to express not only p is true but also statements like p is known or p is necessary true. There are a variety of Modal Logics providing both their semantics and there axioms proof systems [50]

Introduction

Lets say we take a statement from the case study scenario of knowledge sharing, if we consider the statement agent i knows a fact (information) we can think in particular of the ways in which we might intend its truth or falsity e.g. "is it necessary the agent knows a fact" "it is known that agent i knows a fact" "It is believed that agent i knows the fact" "Does the agent know the fact" "or the agent will know the fact in the future" "If the agent flys to another country will he still know the fact. All of these modifications of initial assertions are called by logicians "modalities" Indicating the mode in which the statement is said to be true. The statements are not easily handled by the truth tables and propositional variables as we use in propositional logic and epistemic logic [50]. These are used propositional calculus (PC) these are from the introductory logic. So logicians have created an augmented form called "Modal Logic". This provides mathematicians, computer scientists and philosophers with the symbols and semantics needed to allow for rigorous proofs involving modalities, covering something that until recently was thought to be at best pointless and at worst impossible.

We will provide an introductory discussion of modal logic and a brief history and motivations of modal logics we will also give examples of definitions and concepts.

As with its classical cousin, the modern interest in modal logic begins with Aristotle. In addition to his syllogisms dealing with categorical statements, the Greek thinker wished to formalize the logical relationships between what is, what is necessary, and what is possible. Unfortunately his treatment of modality suffered from a number of flaws and confusions, and while his categorical syllogisms became a staple of classical education, modal logic was dismissed as a failure and it was argued that modalities added no pertinent information to an argument, merely hinting at why we might believe a given statement to be true and believe that no more or less could be derived from the modal form a statement P that from P itself [50]. This claim has come to be seen as false. After all, if two statements are equivalent, they ought to imply each other. It seems reasonable to say that if P is the case then P must be a possible state of affairs, since what is true cannot be impossible. However, it is quite a bit less obvious to say that because P is possible, P is the case. It is possible, for example, that my work colleague friend Bob is actually a very hirsute woman, yet there is no reason to believe that this is actually true. So while actuality implies possibility, possibility does not imply actuality. It seems, then, that there is more to modality [50]. With the growing acceptance of such arguments in the past 50 years or so, there has been a revival of interest in modal logic, the product of which has been a number of interesting new modalities. Temporal logic, for instance, considers whether P is true now, will be true at some point in the future, or has been true in the past. This is actually a multi-modal logic since it uses a number of modes of truth within a single language. Epistemic logic the logic of knowledge and knowing can also be multi-modal. The modality in this case is that of whether agent A knows P or, alternatively, whether P could be true given what A knows. Related is the interpretation of □ which reads □ P as P is provable, a reading that has great use in the field of mathematical logic.

Propositional Modal Logic

Any complete system of logic needs at least three components: a rigorous language for writing out the statements in question, a means of interpreting the statements and determining their truth value, and a means of writing proofs. any language, be it English, Chinese, or the language of logic, must have symbols and rules for combining them. In a spoken language the symbols are words and the rules are grammar. Our case is analogous, although rather than inventing a new system from whole cloth, modal logic begins with the familiar language of PC and just adds two new operators to handle modality. The result is the following set of symbols: A countably infinite set of letters A, X, P1 , P2 , called propositional variables; The unary operators □, ◊, and ¬; The binary operators →, , and ; and Brackets (, and)

We read , ◊, □, ¬, ∧ ∨, , and → as box, diamond, not, or, and, and implies. □ and ◊ are, of course, our new, modal operators. Their generic names allow us to create a single, rigorous system that can be adapted for the various modalities we may wish to implement. All these names are, of course, merely names thus far. We have not yet bestowed on them any formal interpretation. The next step, then, is to define which combinations of these symbols are legal which strings make sense given the interpretation we would like to eventually give. These rules reflect the intuition that tells us that (P Q) is a good formula, yet) P Q is symbolic gibberish. These good formulae we will call well-formed formulae, or wffs for short. A well-formed formula or wff is any formula that meets one of the following three rules. Any propositional variable P standing alone is a wff. When α is a wff, so are $(\neg\alpha)$, $(\Diamond\ \alpha)$, and $(\Box\ \alpha)$. When α and β are both wffs, so are $(\alpha\ \ \beta)$, $(\alpha \wedge \beta)$, and $(\alpha \rightarrow \beta)$ note the recursion of this definition, first defining a base case (called the atomic formulae) and going on to define more complex formula in terms of those wffs already known to us. This will give us a powerful tool for future proofs where we first prove something about isolated propositional variables and go on to show that it holds for the second and third formation rules listed above. This is called induction on the complexity of a formula, and will play a crucial role in our proofs for soundness and completeness below.

2.2. Determination of Truth. In PC we are primarily interested in the tautologies. These are the formulae that are true no matter what the truth of the propositions involved, things like $(P \wedge Q) \rightarrow P$ and $P \wedge \neg\ P$. These are called the valid formulae of PC and are determined by simply checking the truth table for the formula in question. For example, we can tell that $P\ \wedge\ \neg\ P$ is valid because every line of truth table comes out to T. The situation for modal logic is somewhat more complex. After all, the whole point of our new symbols is to indicate a judgement that is independent of the truth of the formula in question. Nonetheless, we want an extension of the same intuitive notion: that the valid formulae are those that are True no matter what or True in all situations. The difference is that now it is possible that some propositions, while not tautological, will always evaluate true. For example, it has been a popular move in theology to claim that it is necessary that there exist a greatest conceivable being. Such theologians are not generally claiming that Gods existence is a tautology, but rather that in every conceivable world the proposition God exists is true. Therefore, they argue, it is a necessary truth that God exists.

It is this reading of necessarily true as true in all possible worlds that lead to the most popular interpretation of modal logic: Kripkes many world semantics. Under this interpretation, the truth of a statement is relative to the world in question. For propositional formulae, this is determined simply by examining the state of affairs in that world. So if P and Q are both true in the current world, $P \wedge Q$ will be true in this world. The more interesting case comes with our new operators, $\Box$ and$\Diamond$. P is defined to be true in a world whenever P is true in all accessible worlds. How we define accessibility depends on the modality, but conceivable is a common one for the necessary/possible modality. So if P is true in all conceivable worlds, P is true that is,$\Box$ P is necessarily true. $\Diamond$ P is similar, although in this case the modality is that of possibility. If P is true in at least one accessible world, $\Diamond$ P will be true as well since it is true somewhere, it must not be impossible. To consider another example, say we were using P to mean X believes P , where X is some person or ideology. The possible worlds here are not really worlds at all, but people, ideologies, institutions anything that can be said to believe a proposition. Accessibility in this case is interpreted as trusts. So if Platonists trust physics, then physics is accessible to Platonism. More elaborately, say that Russell is a node in this network of people and ideologies. For this example, say Russell trusts physics, Richard Rorty, and atheism exclusively. Then P is only true for Russell if P is true for physics, Richard Rorty, and atheism. If P is not true in any one of these, than Russell does not believe P . Similarly, if only Richard Rorty believes P , then $\diamond P$ is true for Russell. He can see how one would believe P , but is not fully convinced. Finally, note that the truth or falsehood of P in Scientology will have no effect on what Russell believes because he does not trust it Scientology is not accessible to Russell by the relation trusts. With these examples in mind, we can now rigorously define the semantics of our symbols.

The formal framework of modal logic provides an insight into relational structures which we use for modelling communication among agents. The syntax and semantics of modal logics is given below. We compare this to epistemic logic, there is the difference in modalities e.g. possibly $\Diamond$ and necessarily $\Box$ Joseph and Halpern [50]. The language of epistemic logic uses knowledge modalities which capture the semantics of knowledge. We will discuss the syntax and semantics for modal logic and the axioms used.

The modal logic language is based on formal principles that impose some requirements over a knowledge representation language to be logic. Modal logics is concerned with propositions and their interrelationships. A proposition is a possible condition of the world about which we want to say something. The condition does not have to be true in order to talk about it Joseph and Halpern [50].

In the next section we will discuss the syntax semantics of logics.

2.2.1 Syntax

The basic modal language can be defined by using a set of proposition letters or (proposition symbols or propositional variables) for example ϕ whose elements are usually denoted p, q, r and the unary modal operator $\Diamond$. The well formed formula's ϕ of the basic modal language are given below by the rule $\phi ::= p \mid \perp \mid \neg\phi \mid \psi \vee \phi \mid \Diamond\psi$ Joseph and Halpern [50]. Where p ranges over elements of ψ, this definition means that a formula is either a proposition letter, the propositional constant falsum (bottom), negated formula, a disjunction of formula's, or a formula prefixed by a diamond. Within logic formulas first-order logic existential and universal quantifiers are duals to each other (in the same sense that $\forall x\alpha \leftrightarrow \neg\exists x\neg\alpha$, we have a dual operator $\Box$ for our diamond which is defined by $\Box\phi := \neg\Diamond\neg\psi$ Joseph and Halpern [50].

2.2.2 Semantics

Semantics is defined in terms of possible-world structures, also called Kripke structures. A (single-modality) Kripke structure is a pair $(\mathcal{W}, \mathcal{R})$, where $\mathcal{W}$ is a collection of, not necessarily distinct, classical propositional models, i.e., models that give a truth value to all sentences that do not contain $\Box$, and $\mathcal{R}$ is binary possible-world relation on these models. Each $w \in \mathcal{W}$ is called a possible world. $\mathcal{R}$ is called the accessibility relation, and sometimes also the reach-ability relation or accessibility relation. It is convenient to think of Kripke structures as directed graphs, with the alternative relation being the nodes of the classical model, and the arcs representing accessibility Yoav and Kevin [96].

We have discussed the language of modal logics, its syntax and semantics and we will compare with the language we use for formalisation of streams which is the language of epistemic logic, its syntax and semantics, as it is the natural choice for modelling knowledge and its axiomatisation.

2.3 Epistemic Logic – Syntax and Semantics

This section discusses the language used to formalise streams, and its syntax and semantics. Epistemic logic is the logic of knowledge and belief Blackburn et al [76]. It allows modelling of the properties of individual knowers within complicated scenarios.

Epistemic logic started with the recognition that expressions like "knows that" or "believes that" have systematic properties that are open to formal study Joseph and Halpern [50]. In addition to its relevance for traditional philosophical problems, epistemic logic has many applications in computer science and economics. Examples range from robotics Falgin et al [40], network security and cryptography Hendrick [42], to the study of social and collisional interactions of various kinds Blackburn et al [76].

Epistemic logic focuses on propositional knowledge. Here, an agent or a group of agents bears the propositional attitude of knowing some proposition. So, when one says: "A manager knows the strategic plan of the company", one is asserting that *manager* is the agent who bears the propositional attitude of knowing the proposition expressed by "manager knows the strategic plan". Epistemic logic also suggests ways to systematise the logic of questions and answers (manager knows what direction his company is heading) and provides insights into the relationships between multiple modes of identification. Epistemic logicians have found ways to formally treat a wide variety of knowledge claims in propositional terms Joseph and Halpern [50].

Possible world Semantics

A model $\mathcal{M}$ for the language $\mathcal{L}_N^K$ comprises a non-empty set $\mathcal{S}$ of possible worlds (or states), $\mathcal{N}$ binary relations $\mathcal{R}_1, \ldots, \mathcal{R}_N$ on $\mathcal{S}$, one for each agent, and a valuation function $\mathcal{V}$: Atom $\mapsto$ Pow ($\mathcal{S}$). The satisfaction relation $\models$ is defined recursively on $\mathcal{L}_N^K$ [28] as follows :

$\mathcal{M}, s \models \phi$ iff s $\in \mathcal{V}(\phi)$ for all atomic formulae $\phi \in$ Atom

$\mathcal{M}, s \models \neg\alpha$ iff $\mathcal{M}, s \not\models \alpha$ i.e., it is not the case that $\mathcal{M}, s \models \alpha$

$\mathcal{M}, s \models \alpha \rightarrow \beta$ iff $\mathcal{M}, s \not\models \alpha$ or $\mathcal{M}, s \models \beta$

$\mathcal{M}, s \models \mathcal{K}_i\alpha$ iff for all t $\in S, s\mathcal{R}_i t$ implies $\mathcal{M}, t \models \alpha$.

The relations $\mathcal{R}_1, \ldots, \mathcal{R}_N$ are called relations of epistemic alternatives, or accessibility relations. A formula α is said to be valid with respect to a class of models if for each model $\mathcal{M}$ in that class and each world $s \in \mathcal{S}$ then $\mathcal{M}$, $s \models \alpha$.

2.3.1 Possible-Worlds Structure

In the possible-worlds concept, the actual world is considered to be one of many possible worlds. For each distinct way the world could have been, there is said to be a distinct possible world; the actual world is the one we live in. Among theorists, there is disagreement about the nature of possible worlds; their precise ontological status is disputed and especially, the difference if any, in ontological status between the actual world and all other possible worlds. There is a close relation between propositions and possible worlds. Every proposition is either true or false in any given possible world; so the modal status of a proposition is understood in terms of the worlds in which it is true and worlds in which it is false.

The basic assumption is that any acknowledgement of propositional attitudes like knowledge and belief, involves dividing the set of possible worlds in two: those worlds compatible with the attitude in question and those that are incompatible with it. The set of worlds accessible to an agent depends on his or her informational resources at that instant. It is possible to capture this dependency by introducing a relation of accessibility, r, on the set of possible worlds. To express the idea that for agent i, the world w is compatible with his information state, or accessible from the possible world w', which i is currently in, it is required that r holds between w and w'. This relation is written $\nabla ww'$ and reads "world w' is accessible from w". The world

w' is said to be an epistemic or doxastic alternative to world w for agent i, depending on whether knowledge or belief is the considered attitude. Given the above semantical interpretation, if a proposition a is true in all worlds that agent i considers possible then i knows a Benthen [9].

Within logic formulas a system can be obtained by adding additional principles, which express the desirable properties of the concept of knowledge. The perception to be captured is that a process knows a given fact at a certain point in a system. If a fact is true at all other points in the system, where the process has the same local state, then there is a set of ϕ, of primitive formulae, which can be thought of as describing basic facts about the system. Starting with the basic facts in ϕ, the language can be extended with formulae that expresses conjunctions, negations and statements about the knowledge. Thus, if ϕ and ψ are formulae, then so are $\phi \wedge \psi$, $(\neg\psi)$, and $K_i\psi$, which reads agent i knows ψ.

The rules of epistemic logic were used by Adamatzky [3] for assigning personal cognitive modalities of meanings and the K operator was used to assign knowledge to the agents Adamatzky [3]. The axioms used are adapted to suit the knowledge management framework by replacing the belief operator (B) with (K), for *knows*, as the axioms will be dealing with what the agents know.

There is a combination of ten axioms (rules) that are used to formalise the knowledge-sharing and knowledge gap streams. First, the knowledge-sharing stream is considered and later the knowledge gap stream. The axioms from Adamatzky [3], which deal with the belief operator, are presented are used to distribute belief among the agents in Adamatzky [3]. The knowledge operator will be used to formalise the knowledge exchange in streams. It is possible to use the knowledge axioms to give a property of knowledge and a proposition, which can be applied to any scenario. There are positive axioms that only state true facts, e.g. an agent knows what is true, and negative ones, for when an agent is aware of what he does not know.

2.4 The Properties of Knowledge

The following properties of knowledge are provided by Hintikka [44] Assuming that $\mathcal{K}_i$ is an equivalence relation and a few properties of knowledge can be derived. The properties listed below are often known as the "S5 Properties" Adamatzky [3].

2.4.1 The Distribution Axiom

The distribution axiom is traditionally known as "K". In epistemic logic terms., this means if an agent knows φ and knows that $\varphi \rightarrow \psi$, then the agent must also know ψ. So, $(K_i\varphi \wedge K_i(\varphi \rightarrow \psi)) \rightarrow K_i\psi$ Hintikka [44].

2.4.2 The Knowledge Generalisation Rule

We can derive another property of knowledge if ϕ is valid, then $\mathcal{K}_i\varphi$. This does not mean that if ϕ is true, that agent i knows ϕ. This means if ϕ is true in every world that an agent considers to be in a possible world, then the agent must know ϕ in every possible world. This principle is called "N": if M $\models \varphi$ then $M \models K_i\varphi$ Hintikka [44].

2.4.3 The Knowledge or Truth Axiom

This axiom is also known as "T". It states that if an agent knows the facts, then the facts must be true. This is the major distinguishing feature between knowledge and belief. We can believe a fact to be true when it is false, but it would be impossible to "know" a false statement: $K_i\varphi \rightarrow \varphi$ Hintikka [44].

2.4.4 The Positive Introspection Axiom

The positive introspection property has introspection about its own knowledge are axioms and are traditionally known as "4" and "5", respectively.

The positive introspection axiom, known as the KK Axiom, states specifically that agents "know what they know". $K_i\varphi \rightarrow K_iK_i\varphi$ Hintikka [44].

2.4.5 The Negative Introspection Axiom

We now present the negative introspection axiom 5 which states that agents "know what they do not know": $\neg K_i\varphi \rightarrow K_i\neg K_i\varphi$ Hintikka [44].

2.4.6 Axiom systems

Different systems of modal logic can be derived by using different subsets of these axioms and a system e.g. KT45, the modal logic that results from using "K", "T", "4", "5", and the knowledge generalisation rule, is primarily known as S5 (modal logic). This is why the properties of knowledge, described above, are often called the S5 Properties Hintikka [44].

Epistemic logic also deals with belief, not just knowledge. The basic modal operator is usually written “B” instead of “K”. In this case though, the knowledge axiom no longer seems right – agents only sometimes believe the truth – so it is usually replaced with the consistency axiom, traditionally called “D”: $\neg B_i \bot$ which states that the agent does not believe a contradiction, or that which is false. When “D” replaces “T” in S5, the resulting system is known as KD45. This results in different properties for $\|_i$ as well. For example, in a system where an agent “believes” something to be true, but which is not actually true, the accessibility relation would be non-reflexive. The logic of belief is called doxastic logic Hintikka [44]. We now present the knowledge axioms which are the standard axioms used to represent knowledge.

The axioms can be rewritten by replacing the B operator with the K operator and eliminating the t prefix, which represents time. We are able to change the B axiom to the K axiom as we want to talk about knowledge. This is possible as we use the same alphabet Joseph and Halpern [50]. The axioms on the next page are used in the knowledge management model for formalisation purposes.

Knowledge axioms used:

- (K1) $K_i \neg \neg \alpha \rightarrow K_i \alpha$ Agent i knows that it is not the case not α, which implies agent i knows α.

- (K2) $\neg\ K_i\ \neg\ \alpha \rightarrow K_i\ \alpha$ It is not the case agent i does not know not α, implies agent i knows α.

- (K3) $\neg\ K_i\alpha \rightarrow K_i\ \neg\ \alpha$ It is not the case agent i knows α, implies agent i knows α.

- (K4) $K_i\ \alpha \rightarrow K_i\ K_i\ \alpha$ Agent i knows α, implies agent i knows that it knows α.

- (K5) $K_i\ \alpha \wedge K_i\ (\alpha \rightarrow \beta) \rightarrow K_i\ \beta$ Agent i knows α and agent i also knows β, implies agent i knows β.

- (K6) $K_i\ (\alpha \wedge \beta) \rightarrow K_i\ \alpha \wedge K_i\ \beta$ Agent i knows α and β, implies agent i knows α and agent i knows β.

- (K7) $K_i\ (\alpha \vee \beta) \rightarrow K_i\ \alpha \vee K_i\ \beta$ Agent i knows α or β, implies agent i knows α or agent i knows β.

- (K8) $K_i\ \neg\ (\alpha \wedge \beta) \rightarrow K_i\ \neg\ \alpha \vee K_i\ \neg\ \beta$ Agent i knows not α and β, implies agent i knows not α or agent i knows not β.

- (K9) $K_i\ \neg\ (\alpha \vee \beta) \rightarrow K_i\ \neg\ \alpha \wedge K_i\ \neg\ \beta$ Agent i knows not α or β, implies agent i knows not α and agent i knows not β.

- (K10) $K_i\ K_j\ \alpha \rightarrow K_i\ \alpha$ Agent i knows that agent j knows α, which implies agent i knows α.

Among the various approaches to epistemic logic that have been proposed, the modal approach has been the most widely used for modelling knowledge.

The reason for this popular approach is its simplicity: systems of modal logic are given an epistemic interpretation and the main technical results of epistemic logic can be used.

Suppose that there is a group consisting of N agents. The language of propositional logic can be augmented by N knowledge operators $K_i, \ldots, K_N$ (one for each agent). A formula like $K_i\alpha \wedge K_i(\alpha \rightarrow \beta) \rightarrow K_i\beta$ is interpreted: "if agent i knows α and $\alpha \rightarrow \beta$ then he knows β". Formally the language $\mathcal{L}_N^K$ of modal epistemic logic is defined as follows:

Definition 2.4.1 *epistemic logic is specified by the following axioms and rules of inference:*

The following axioms are often considered N. Duc [28]:

(T) $K_i\alpha \rightarrow \alpha$.

(D) $K_i\alpha \rightarrow \neg K_i\neg\alpha$.

(4) $K_i\alpha \rightarrow K_iK_i\alpha$.

(5) $\neg K_i\alpha \rightarrow K_i\neg K_i\alpha$.

The formula (T) states that knowledge must be true and this property is to be the major one distinguishing knowledge from belief. An agent can have false beliefs but you can not know something that is not true, therefore (T) is the knowledge axiom or the truth axiom. The property (D) is called the consistency axiom, and requires that agents be consistent in their knowledge. It is often the case that the formula $\neg K_I(\alpha\wedge\neg\alpha)$ is used instead of (D). These two formulae are similar in all logic systems containing $K_i\alpha\wedge K_i\beta \leftrightarrow K_i\alpha\wedge\beta$, in particular in all normal modal systems N.Duc [28].

The properties (4) and (5) are called positive and negative introspection axioms. These state that an agent is aware of what he knows and what he does not know.

We have discussed the language of epistemic logic and the properties of knowledge which formalises the process of streams. We have also discussed how it is possible to convert the belief axiom to knowledge. We now translate the epistemic language used for formalisation to MAP language which allows us to analyse the protocol conversation and the content of the dialogue.

2.5 MAP Language – Syntax and Semantics

The Multi agent protocol (MAP) language is a lightweight dialogue protocol to represent multi-agent dialogue, which is a replacement for the state-chart representation of protocols in electronic institutions [1]. The MAP language is used to represent a dialogue for an auction negotiation protocol. In this research we use the MAP language in a similar way to represent the knowledge sharing and knowledge gap protocol to represent how the knowledge exchange works.

A scene can be thought of as a bounded space in which a group of agents interact on a single task. The importance of using the MAP language is that it enables us to divide a large protocol into manageable sets. For example, the knowledge-sharing scene may be part of a larger group as it can consist of more than two agents. Using MAP allows a certain measure of security, as it includes the agents that are in the scene and excludes the ones that are not relevant.

Additional security measures can be placed or introduced into the scene, e.g. by placing entry and exit conditions on the agent. If a barrier condition is placed on the agents, such a scene cannot begin until all the agents are present, and the agents cannot leave the scene until the dialogue is completed.

The abstract syntax is shown in Table 2.4. A scene protocol $\mathcal{P}$ is uniquely n and defined as a (non-empty) sequence of roles r each of which defines a set of methods $\mathcal{M}$ which sets the scene. The agents have a fixed role for the duration of the protocol. Agents are individually identified by unique names, e.g. a or b. A method $\mathcal{M}$ can be considered a procedure where $\phi^{(k)}$ are arguments. The initial protocol for an agent is specified by setting $\phi^{(k)}$ to be empty (i.e. $\mathcal{K} = 0$, which basically means that a process will start with an initial state) also known as the empty state. The protocols are constructed from operations known as $0p$ actions. This controls the flow of the protocol and the actions α that have side affects and can result in failure. The interface between the protocol and the rational processes of the agent is achieved through the invocations of decision procedures p.

The procedures and performatives are parametrised by terms, which are either variables v, agent names a, role names r or constants c. Variables are bound to terms by unification, which occurs in the invocation of procedures, the receipt of messages or through recursive actions. The different types of terms are distinguished by prefixing the names of the variables which are illustrated in Table 2.4 presents the MAP syntax that will be used and the scene will be the set of agents that are involved in the knowledge-sharing and

Table 2.4: MAP abstract syntax

$P ::= n(rM)+$	(Scene)
$M ::=$ method $(\phi^{(k)}) =$ op	(Method)
op $::= \alpha$	(Action)
$\mid$ op1 then op2	(Sequence)
$\mid$ op1 or op 2	(choice)
$\mid$ op1 par op2	(Parallel)
$\mid$ waitfor op1 timeout op2	(Iteration)
$\mid$ call $(\phi^{(k)})$	(Recursion)
$\alpha ::= \varepsilon$	(No action)
$\mid v = p(\phi^{(k)})$	(Decision)
$\mid M =>$ agent $(\phi^1\phi^2)$	(Send)
$\mid M <=$ agent $(\phi^1\phi^2)$	(Receive)
$M ::= p(\phi^{(k)})$	(Performative)
$\phi ::= \_ \mid a \mid r \mid c \mid v$	(Terms)

knowledge gap process C. Walton [93].

2.5.1 Operational Semantics of MAP

The natural semantics style is useful because the entire evaluation of an agent dialogue can be captured. Relations between the initial and final states of the program fragments are now defined. A program fragment in MAP is either an operation *op*, or an action α. The state is captured by an agent environment Δ C.Walton [92].

The operational semantics of MAP are shown in Figure 2.1. The environment contains an n-tuple for each agent comprising the agent role r, the agent protocols a e, the bound variables v e, the decision procedures p e, and a message queue m $e^{(k)}$. The agent protocols a e map from arguments

$\phi^{(k)}$ to operations *op*, where an empty sequence of arguments is the initial agent protocol. The decision procedures $p\ e$ are represented as a map from the procedure name p to the argument terms $\phi^{(k)}$. The message queue m $e^{(k)}$ is a sequence of n-tuples $(a;\ r;\ m)$, where a and r are the name and role of the sender, and m is the actual message. To model the exchange of messages among agents, it is assumed that the environment Δ is shared between agents, thus sending a message to an agent is modelled by placing the message into the message queue $m\ e^{(k)}$ of the recipient. Rules 1 through 6 define the evaluation of the different types of operations *op*. The form of these rules is $(\Delta, a \vdash op \Rightarrow \Delta')$, where Δ is the state at the start of evaluation, a is the name of the agent performing the evaluation, *op* is the operation, and Δ' is the state on completion. Similarly, rules 7 through 10 model the evaluation of the actions α. The form of these rules is $\Delta, a \vdash \alpha \Rightarrow \Delta'$, which is as before where α is the action.

A substitution function, $v\ e \vdash \text{subst}(\phi) \Rightarrow \phi'$, is defined, which substitutes variables for their values, and a unification function $v\ e$ 'unify $(\phi_1{,}\phi_2)$ $v\ e$', which matches terms and binds variables to values. The $v\ e \vdash$ '$eval\ (p;\ v) \Rightarrow$ $v\ e$' function evaluates the external decision procedure p, binding the result to v in $v\ e$. For example, rule 2 states that the delta environment Δ is in a zero state after the agent has performed operation 1 and operation 2, this puts the Δ environment in a prime 2 position, which means the environment is in a different state, e.g. an action could be performed. The line above rule 2 indicates that the agent performs an action in Δ and an operation has been performed. Next comes Δ', from which the second operation is performed, and which puts Δ' into double prime, which is in a different state again from operation 1. We can establish correlation between epistemic and operation semantics as done in M. Mousavi [29].

We have discussed the MAP language and its syntax and semantics which identify the operational semantics of the protocol and the relation between agents and its environments. We now discuss the SPIN Model checking.

$$\boxed{\Delta, a \vdash op \Rightarrow \Delta'}$$

$$\frac{\Delta, a \vdash \alpha \Rightarrow \Delta'}{\Delta, a \vdash \alpha \Rightarrow \Delta'}\ \mathbf{(1)}$$

$$\frac{\begin{array}{l}\Delta, a \vdash op_1 \Rightarrow \Delta' \\ \Delta', a \vdash op_2 \Rightarrow \Delta''\end{array}}{\Delta, a \vdash op_1\ \texttt{then}\ op_2 \Rightarrow \Delta''}\ \mathbf{(2)}$$

$$\frac{\Delta, a \vdash op_1 \Rightarrow \Delta'}{\Delta, a \vdash op_1\ \texttt{or}\ op_2 \Rightarrow \Delta'}\ \mathbf{(3)}$$

$$\frac{\Delta, a \vdash op_2 \Rightarrow \Delta'}{\Delta, a \vdash op_1\ \texttt{or}\ op_2 \Rightarrow \Delta'}\ \mathbf{(4)}$$

$$\frac{\begin{array}{l}\Delta, a \vdash op_1 \Rightarrow \Delta' \\ \Delta, a \vdash op_2 \Rightarrow \Delta''\end{array}}{\Delta, a \vdash op_1\ \texttt{par}\ op_2 \Rightarrow \Delta' \cup \Delta''}\ \mathbf{(5)}$$

$$\frac{\begin{array}{l}\Delta(a) = (r, AE, VE, -, -) \\ VE \vdash subst(\phi_1^{(k)}) \Rightarrow \phi_2^{(k)} \\ \exists \phi_3^{(k)} \in AE\ | \\ \quad \{\emptyset \vdash unify(\phi_3^{(k)}, \phi_2^{(k)}) \Rightarrow VE'\} \\ \Delta \cup VE', a \vdash op \Rightarrow \Delta'\end{array}}{\Delta, a \vdash \texttt{agent}(\phi_1^{(k)}) \Rightarrow \Delta'}\ \mathbf{(6)}$$

$$\boxed{\Delta, a \vdash \alpha \Rightarrow \Delta'}$$

$$\frac{}{\Delta, a \vdash \epsilon \Rightarrow \Delta}\ \mathbf{(7)}$$

$$\frac{\begin{array}{l}\Delta(a) = (r, -, VE, PE, -) \\ VE \vdash subst(\phi_1^{(k)}) \Rightarrow \phi_2^{(k)} \\ VE \vdash unify(PE(p), \phi_2^{(k)}) \Rightarrow VE' \\ VE' \vdash eval(p, v) \Rightarrow VE''\end{array}}{\Delta, a \vdash v = p(\phi_1^{(k)}) \Rightarrow \Delta \cup VE''}\ \mathbf{(8)}$$

$$\frac{\begin{array}{l}\Delta(a) = (r, -, VE, -, -) \\ VE \vdash subst(\phi_1^{(k)}) \Rightarrow \phi_3^{(k)} \\ VE \vdash subst(\phi_2^{(2)}) \Rightarrow \phi_4^{(2)} \\ \qquad \forall a' \in \Delta(a)\ | \left\{\begin{array}{c}\Delta(a) = (r', -, VE', -, ME'^{(k)}) \\ \emptyset \vdash unify(\phi_4^{(2)}, (a', r')) \Rightarrow \emptyset\end{array}\right\}\end{array}}{\Delta, a \vdash \rho_1(\phi_1^{(k)})\ \texttt{=>}\ \texttt{agent}(\phi_2^{(2)}) \Rightarrow \Delta(a') \cup (a, r, \rho_1(\phi_3^{(k)}))}\ \mathbf{(9)}$$

$$\frac{\exists ME \in \Delta(a).\ | \left\{\begin{array}{c}\{ME = (a', r', \rho_2(\phi_3^{(k)})) \\ \emptyset \vdash unify((a', r'), \phi_2^{(2)}) \Rightarrow VE \\ VE \vdash unify(\phi_1^{(k)}, \phi_3^{(k)}) \Rightarrow VE'\}\end{array}\right\}}{\Delta, a \vdash \rho_1(\phi_1^{(k)})\ \texttt{<=}\ \texttt{agent}(\phi_2^{(2)}) \Rightarrow (\Delta - ME) \cup VE'}\ \mathbf{(10)}$$

Figure 2.1: Operational MAP semantics

2.6 Model Checking in SPIN

SPIN is a generic verification system which supports the design and verification of communication process sys- tems. SPIN verification models are focused on proving the correctness of process interactions, and they at- tempt to abstract as much as possible from internal sequential computations. Process interactions can be specified in SPIN with rendezvous primitives, with communication message passing through buffered channels, through access to shared variables, or with any combination of these. In focusing on asynchronous control in software systems, rather than synchronous communication control in hardware systems, SPIN distinguishes itself from other well-known approaches to model checking [45]. As a formal methods tool, SPIN aims to provide:

1) an intuitive, program-like notation for specifying de- sign choices unambiguously, without implementation detail, 2) a powerful, concise notation for expressing general correctness requirements, and 3) a methodology for establishing the logical consistency of the design choices and the matching cor- rectness requirements.

We will be using SPIN to model check our KM processes as SPIN is highly optimised and widely used software tool fopr efficient verification. Common errors detected by model checker are livelock, startvation, under specification, resulting in unexpcted reception of message: over specification resulting in dead code, violations of contraints, buffer overrruns. Model checking is an automated technique that given a finite-state model of a system and logical property, systamatically checks whether this property holds for a given initial state in that model Holzmann[45].

Model checking and simulation of knowledge processes requires correct abstraction from the problemis defined in the input language of SPIN (PROMELA). This requires a transition from the problem domain to the concepts used in the model checker such as message passing systems and processes This model must be validated in order to ensure that mo mistakes are introduced by the abstraction. Thereafter the correctness requirements must be formulated in the cprresponding requirements language. We use the PROMELA language (Process Meta Language) as it is used for modelling which make it suitable for modelling of knowledge management process as we will demonstrate in our case studies. The model correctness is checked by peforming random or iterative simulations of the simulations of the execution of the knowledge management processes. During simulations and verifications SPIN checks for the absence of deadlocks, unspecified receptions or non-progress execution cycles. Once verification has been carried out it can be used in the construction and verification of all subsequent models of knowledge exchange. Promela specifications consist of processe, message channels, and variables. Proesses are global objects that that represent the concurrent entities of the distributed system. Message channels and variables can be declared either blobally or locally within a process. Processes speecify behaviour, channels and global variables define the environment.

Model Checking tools automatically verify whether a property f holds in a model M, where M is a finite-state model of a system and the property

f is stated in some formal notation. The notation is selected based on the application. We choose epistemic logic as the natural language for modelling of knowledge. complete with rigorous semantics and well developed interface systems. Although finite state the model of a system typically grows exponentially Kupfermann et al [68]. In our framework exponential model growth is not an issue as we simulate knowledge management processes which terminate in models of limited size. Our approach is based on verification. We try to ascertain the correctness of a detailed model M of the system in our case a multi agent model of a exchange within an organisation involving two or more agents under validation. SPIN assists in analysing the logical consistency of knowledge management processes, modelled as data communication protocols.

In order to achieve verification of knowledge management processes we translate the protocol language spoecification into promela. The translation preserves correctness. Following the translation we check a number of properties of the ubderlying knowledge management processes in the mulyi agent system, such as termination, deadlock avoidance, and process correctness, Our approach is similar to approaches used for modelling multi agent dialogues, agent mediated knowledge management and distributed knowledge management.

We can show that knowledge sharing can be modelled as u multi agent protocol, translated into promela, and model checked. We present a verifiable knowledge exchange between individuals modelled as muli agents. Correctness properties of the exchange can be proved. Our model checking approach allow us to detect internal enterprise knowledge exchange policies that conflict with the process fpr e.g. allowing unauthorised agent to access propriety knowledge and inconsistencies in the process itself e.g. non termination

SPIN (Simple PROMELA Interpreter) is a general open source software tool that is used around the world for verification and distribution of software systems. Development started in 1980 at Bell Laboratories, in the original UNIX group for computing science research. After the release of the first version in 1991, subsequent versions followed each with enhanced capabilities Holzmann [46]. The tool supports a high-level language to specify the system description, called PROMELA (Process Meta Language).

SPIN is used to trace logical design errors in distributed systems design, such as operating systems, data communications protocols Boigelot and Godefroid [10], switching systems, concurrent algorithms, railway signalling protocols Boigelot and Godefroid [39], flood systems and mission critical systems Holzmann [45] etc....... An e.g. is given by Holzmann [46] an application of SPIN is the verification of the control algorithms for the new flood control barrier built in the late nineties near Rotterdam in the Netherlands, carried out by the Dutch firm CMG (Computer Management Group) Holzmann [46].

SPIN checks the logical consistency of a specification and it reports on any deadlocks and unspecified receptions. SPIN also flags any incompleteness, race conditions and unwarranted assumptions about the relative speed of a process Holzmann [46].

The graphical interface of the XSPIN tool and the language used for verification of agent protocols processes will now be presented in Figure 2.2.

The tool allows selection of the options and properties that can be checked. The panel in Figure 2.2 shows the visual control over the options that SPIN provides for performing automated verifications. The initial settings are set in a way that all the parameters are automatically chosen on a default way to provide a reasonable starting point for most of the applications. If for e.g. a verification run is complete, Xspin attempts to give hints about ways to proceed, this is based on the results obtained. Xspin will not provide any hints when a clear run is performed meaning when there are no errors. We will now explain how the verification tool works in Figure 2.2.

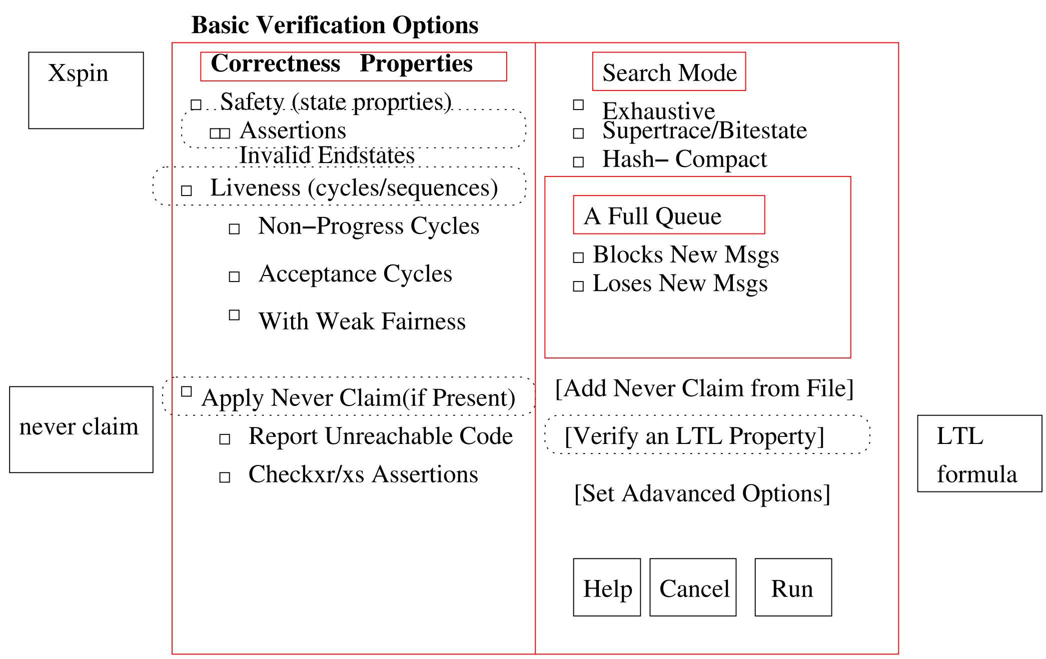


Figure 2.2: Model-checking tool

Basic Verification Options explained

We now present in Figure 2.2 the default settings which define the search for safety properties, proving liveliness properties, this requires a separate verification run with the appropriate options selected in the correctness properties section of the verification parameters panel.

In a distributed system, there are two types of correctness, *Safety* is defined as the set of properties that the system may not violate and *liveliness* is a set of properties that the system must satisfy. A *never-claim* can be used to match either finite or infinite behaviours. Finite behaviour is matched if the claim can reach its final state. Never claims, can be used to verify both safety and liveliness.

Communication via message channels can be defined to be synchronous (i.e., rendezvous), or asynchronous (i.e. buffered).

PROMELA consists of processes, message channels, and variables. Processes are global objects. Message channels and variables can be declared either globally or locally within a process. Processes specify behaviour, channels and global variables define the environment in which the processes run.

SPIN has many unique features that set it apart from other verification systems. Some of these features are listed below:

1. Provides direct support for the use of multi-core computers for model-checking runs supporting both safety and liveliness verification.

2. Works on-the-fly, which means that it avoids the need to reconstruct a global state graph, or Kripke structure, as a prerequisite for the verification of system properties.

3. The tool supports both rendezvous and buffered message passing and

communication through shared memory. Mixed systems, using both synchronous and asynchronous communications, are also supported. Message channel identifiers for both rendezvous and buffered channels, can be passed from one process to another in messagesHolzmann [46].

Model checking is used to automatically verify whether $\mathcal{M} \models \phi$ holds, where $\mathcal{M}$ is a (finite-state) model of a system and property $\mathcal{M} \models \phi$ is stated in some formal notation.

The next section discusses the basics of the PROMELA language and gives an example of basic PROMELA constructs, which involve interaction of processes.

2.7 PROMELA Basics

PROMELA is a modelling language, not a programming language. The simplest form of a PROMELA model is made up of the following components Holzmann [46]:

- Channel declarations: mtype, constants, typedefs.
- Global declarations: asynchronous, rendezvous.
- Variable declarations: simple variables, structured variables. Variables can be accessed globally by all processes.
- Process declarations: behaviour of the process, local variables and statements.

- The init process initialises variables and starts processing.

We now present a sender and receiver example code in PROMELA, and explain each line of the code.

The following example shows a simple sender-receiver with two processes that interact with each other which shows the PROMELA components as shown in Figure 2.3.

Line 1 is a mtype declaration, which declares two symbolic names **s** and **r**, also known as variables. Variables act like containers, which hold values and should be declared. The value that the variable holds is dictated by a specifier in this case, `mtype`. The equals sign between `mtype` and **`s, r`** is an assignment operator, while a double equals (`==`) is a boolean operator. Values are always assigned from right to left. The word `mtype` is used to specify in the declaration the values that will be used within the process. The values **s** and **r** both hold integer values. Following the `mtype` declaration, there is a global declaration of a variable called **turn** of type `mtype` in line 2. A global declaration means that the variable **turn**, which contains the value **s**, can also take any values from the `mtype` declaration.

In line 3 is a declaration of type `proctype`, which creates a process called **sender**. The word `active` before `proctype` is a prefix defining that the process is to be instantiated automatically. In line 5, after the opening brace, there is the keyword `do`, which signifies the beginning of a loop statement followed by optional executable statements.

A statement is either executable or it can be executed immediately. Processes in PROMELA, in general, execute concurrently with all other processes, independently of speed or behaviour, and communicate with other processes by using global (shared) variables using channels. There may be several processes of the same type. Each process has its own local state, which holds the contents of the local variables Holzmann [46].

The loop is terminated by `od`, followed by a closing brace to mark the end of the process definition. The statements between `do` and `od` are the body of the loop. The first statement after the double colon is called a guard statement and is a typical construct of a do loop. The guard statement has a condition, `(turn == s)`, and statements that follow this guard can only be executed if and when the variable **turn** has the value `s`.

Processes are created using the `run` statement as this returns the process `ID`. Processes can be created at any point in the execution with any process. As seen in Figure 2.3, processes in PROMELA can also be created by adding the prefix `active` in front of the `proctype` declaration.

The sender process example only declares the behaviour of the process, it does not execute it. To execute a process, it must be instantiated, which is done by declaring a process explicitly of type `init`. The smallest possible PROMELA specification is `init skip`. In this example, `skip` is a dummy or null statementHolzmann [46].

This example is only a simple one; however, such processes can get more complex, requiring the exchange of data between processes. In PROMELA, the exchange of data is accomplished by the use of message channels. Message channels can have an infinite number of fields per message. A field must be either a user-defined type or predefined, e.g. `but`, `bool`, `byte`, or `mtype`. Arrays Holzmann [46] are used to specify a variable that can be indexed.

A simple channel declaration for asynchronous communication is:

```
Chan qname = [16] of {short, byte, bool};
```

Here, the typename `Chan` defines a channel named **qname**, and is declared to be capable of storing up to sixteen messages.

```
mtype = {s, r};
mtype turn = s;
active proctype sender()
{
     do
     : :  (turn == s) ->
                printf(Sender\n);
                turn = r
     od
}
active proctype receiver()
{
     do
    : :  (turn == r) ->
                printf(Sender\n);
                turn = r
     od
}
```

Figure 2.3: Sender and Receiver example Holzmann [46]

We have discussed the SPIN section which involves the last step of our framework which allowed us to check for any deadlocks and made sure that the processes terminate successfully. We have given the sender and receiver example to show how the verification works by using PROMELA. We now discuss the motivational aspect of the thesis.

Chapter 3

Motivation

This chapter discusses the motivation of the thesis and introduces knowledge management. First we define KM and the benefits associated with KM, along with the challenges in utilising KM. We also describe and compare SMEs and large organisations and how they utilise KM. We have conducted research with companies in respect to how they utilise KM and how they perceive KM in their organisation these companies have been selected as they come under the category of SMEs and large organisations. The results from the questionnaire will assist in critically analysing the how the theoretical aspect of the literature review is compared with the actual research carried out by obtaining results from the questionnaire which was conducted.

It is stated by Davenport and Prusack [23] that managers of companies now understand that they require more than a casual or an unconscious approach to corporate knowledge if they want to compete and succeed in today's markets and in the future. In Davenport and Prusack [23], there are discussions with corporate managers about how knowledge functions in organisations and how research, on new approaches to information management, brought together executives from 25 companies, including Hewlett-Packard, IBM, AT & T and American Airlines. The executives were asked what they most needed to know, what they currently didn't know and how could they be helped to know? Davenport and Prusack [23]. In accordance with the research carried out by completing questionnaires from various industry sectors the above statement mentioned by Davenport is correct in the sense that managers of companies need to understand what KM is before they invest any KM tools.

Traditional economists look at organisations as black boxes, only examining the resources going in, the products going out and the markets in which they participate. Theorist are now turning their attention to the essential dynamics, looking inside the box to see what knowledge is embedded in the routines and practises that the firm transforms into valuable products and services. Our research analyses the flow of information in an organisation and verifies who knows what by using model-checking processes. It is stated by [23] that companies have made costly errors by disregarding the importance of knowledge as per the research conducted. Many firms are now struggling to gain a better understanding of what they know and what to do about it. In accordance to the research carried out all of the companies who participated in the survey where asked what they had thought about knowledge management and if they had heard of knowledge management, all companies stated that they have heard of KM more so the larger companies than the smaller organisations and only knew to a certain extent what KM can do for them. The businesses had indicated that they only know the basics as this backs of the statement "where many companies struggle to gain a better understanding of KM. Organisations mistakenly assumed that technology could replace the skill judgement of an experienced human worker Davenport and Prusack [23]. To assume that technology can replace human knowledge or create its equivalent has been proven false many times. Developments in technology are among the positive factors which fuel interest in knowledge and its management, such as network computing, which provides new ways for individuals to exchange information and knowledge within and outside an organisation Davenport and Prusack [23]. We would agree with Davenport statements in regards to research carried out as all companies agreed they require some sort of systems to deal with KM and exchange information.

But the issue of who knows what and the knowledge flow in an organisation is vital to knowledge management. It is crucial for organisations to know what information their employees hold and the issue of knowing what they know must be addressed.

Research has been conducted in the knowledge management industry, to see how companies perceive knowledge management in different industry sectors, e.g. retail services, law companies and IT companies Maria [57], Nabil and Andrew [65] . It is difficult for owners or managers in small businesses to recognise and acknowledge the need for KM and its benefits [8]. Research was conducted by Beijerse [8] in the Netherlands on how SMEs can benefit from KM. The study primarily focuses on the knowledge management flow and the understanding of KM. Our research in comparison builds a KM framework, susceptible to verification and builds on the streams which Beijerse [8] discusses in his research. Our research analyses the choice of a specific KM streams selected and also formalises these streams as a step towards the verification stage in our KM framework and to allow modelling of the knowledge flow. Knowledge is a key asset in an organisation, but organisations are still at an early learning stage of understanding the implications of knowledge management and understanding the knowledge economy Beijerse [8]. This can be backed up by the research we conducted with by companies filling out questionnaire that companies do realise the benefits of KM but it is hard for managers to acknowledge the need of implementing such systems as they are overly complicated according to their results.

Organisations realise the importance of KM and find ways of using mapping tools more efficiently and effectively Prusack [71]. It is argued by Nonaka [67] that a company needs to know how to share information before it can benefit from KM in comparison to the research carried out where we asked the question in relation to knowledge sharing all organisations stated that it was important to share knowledge with other employees but only necessary information should be shared not the sensitive material. It is agreed by Ching [52] and Nonaka [67] that there needs to be more than just knowledge sharing in an organisation. Organisations need to adopt a learning culture as a part of their learning strategy and this should be implemented at an initial stage. It is agreed that it is difficult to share knowledge in an organisation if there is no learning culture, as no employees in the company will be motivated to learn, see Ching [52] and Nonaka [67].We would agree with the statement that there needs to me more than just knowledge sharing and a learning culture needs to be adopted, the questionnaire indicated that in the smaller organisations there was not much of a learning culture of knowledge management as the organisations were primarily concerned with their daily operation of the business.

KM is increasingly being used in large organisations in comparison to SMEs as they are still at the stage of knowing what KM is and how it can help SMEs this statement can be backed up by the results achieved from the questionnaire as the SMEs had stated they have heard of KM but one of the companies did not see it as being part of their strategy. It is necessary for SMEs and large organisations to understand the knowledge economy and how this effects them. It is also stated by Prusack [71]: "The idea of KM has received an upsurge of interest in the recent years as knowledge being a valuable source to an organisation's ability to innovate and compete."

The next section discusses the importance of KM, defines SMEs and large organisations and shows how they differentiate from each other. The chapter also discusses the organisational structure, management, culture and resources of organisations.

3.1 Importance and Benefits of Knowledge Management

Many large companies perceive KM as a critical component of their organisation and product innovation as it has provided the organisations with a critical KM tool to help their employees learn using the KM database we can agree with this statement as per to our questionnaire the results showed that larger organisations do perceive KM as a critical part of their organisations but still face challenges e.g. understanding the complexity of such systems. These examples show that it can be easier to implement a KM strategy as long as the potential benefits of KM and how it can be implemented are known.

However, it is also argued by Prusack [71] that some organisations have benefited from KM and others have failed to implement KM tools and have not succeeded, due to a lack of understanding of KM and how it should be used strategically we would agree with Prusack as some organisations do not know or have limited knowledge of KM and how they can benefit from KM according to the questionnaires completed in relation to KM for our research. Organisations, small or large, need a KM framework, so they can understand what knowledge is flowing in the organisation and take necessary actions to lock or utilise the knowledge Prusack [71]. The framework should include an approach to knowledge management that is specifically tailored to the organisation's environment, processes and goals.

In line with what has been identified as essential for effective KM in organisations, our research proposes a framework that has been developed with specific knowledge management instruments, also known as questionnaires, which organisations select, depending on their specific needs.

It is stated by Prusack [71], further motivation for having such a KM framework is provided by the following six factors:

- Reduction in the time needed by employees to acquire new knowledge.
- A growing emphasis on creating customer value and improving customer service.
- An increasingly competitive market place with a rising rate of innovation.
- Reduced cycle times and shortened product development times.
- A need for organisational adaptive because of changing business rules and assumptions.
- A requirement to operate with the minimum level of assets, e.g. people, inventory and facilities.

The next section discusses why it is important for SMEs and large organisations to use KM initiatives.

3.2 Why Organisations Need KM ?

It is stated by Kuwan and Aspinwall [51] that the integrative concept of KM is perceived to have the potential to enable organisations to face complexities and changes, by enveloping them in the knowledge-based economy. One of the reasons why SMEs and large organisations need KM can be traced to a pull-and-push perspective. The pull perspective identifies the potential benefits or improvements, which are crucial for small and large businesses, while the push perspective deals with the external or environmental thrusts that push them to the forefront of KM. With the pull perspective Prusack [71] states that a great deal has been mentioned in the literature about how knowledge is viewed as a key resource and a strategic asset that can contribute to the improved performance of an organisation. According to the questionnaires filled out some of the companies did not know what was KM until it was explained to them in detail what it meant and what practices are carried out that can be categorised as KM all of the organisations viewed KM as a important asset to the their organisations although one of the companies thought it was just a management fad and did not pay too much attention to it. According to Welsh and White [94], it is not possible for SMEs to compete with large companies in terms of tangible resources such as capital, labour, equipment and physical commodities. However, it is possible for SMEs to compete, but on a smaller scale and they still need to manage knowledge efficiently Maria [57]. We would like to state that according to the results from the questionnaire we can agree with Welsh that it is harder for smaller organisations to compete with larger organisations in respect to implementing KM systems, the results from the questionnaire revealed that smaller organisations have only basic systems e.g. database systems to manage information and data and are not able to afford larger systems, in comparison larger organisations e.g. Bank of Scotland have more complex systems with advance capabilities.

The next section discusses how SMEs and large organisations can benefit from KM.

3.3 Benefits of Knowledge Management

Imagine knowledge as a fuel for business. Knowledge can be used productively and profitably by organisations in numerous ways. The attractive incentive for the intelligent business person is to figure out how to leverage this asset in new and creative ways in order to gain a serious sustainable competitive edge in the marketplace. Companies have been trying to find ways that help to locate, organise, transfer and leverage knowledge Davis [24]. If we compare this statement with the questionnaires conducted all of the organisations were involved in knowledge management in one form or another some of the smaller organisations had informal systems of sharing information e.g. senior staff training new recruits. However there needs to be more awareness of KM in smaller organisations for them to take advantage of the knowledge which resides in their company.

Companies invest thousands of pounds in creating, using or sharing knowledge Prusack [71]. Most companies use their KM initiatives to increase sales, as per the questionnaire smaller organisations do not know how to increase sales by using the the tools they have and know little about how KM can assist in increasing sales and to reduce response times to customers and to

Advantages and Disadvantages of organisation in KM implementation SMEs		
	Advantages	Disadvantages
Ownership & Management	centralised decision making owners have the authority of implementing a KM strategy The owners can have a improved understanding of KM and the issues relating to it . Able to set good examples of KM	Most managers may not be aware of the KM benefits. Busy on day to day running of their business. Not having relevant skills to deal with KM. Cannot afford KM
Structure	Basic strucutre easier to understand Less comples Direct link to employees Faster implementation	Low degree of specialisation may result in inadequate expertise for implementing KM.
Culture and Behaviour	Easier to implement KM gives a strong foundation. less complex in culture change Easy to manage the knowledge culture change	Authoritative, Uncommitted and knowledge unfriendly personality of owner−managers can be problematic in implementing KM.
Systems, processes and procedures	Easier to train small member of staff Less expensive Faster results from change Easier to manage KM in small groups	Staff may resist towards new systems Lack of formal practices in place Too complex to handle
Human resources	Less employees to deal with Better support fro KM Easy to coordinate	Not being able to assign skilled staff to deal with KM. Lack of educated staff Lack of training practices in work place

Table 3.1: Advantages and disadvantages for organisations using KM

make more effective use of talented and innovative employees. Companies are beginning to understand that the knowledge of their employees is their most valuable asset Prusack [71], but few firms have started to actively manage their knowledge assets on a large scale but it has to be argued that organisations whether large or small still face the increasing challenges of the complex systems which deter the managers to completely understand them.

KM has thus far been addressed at either a philosophical or a technological level, with little pragmatic discussion on how knowledge can be managed and used more effectively on a daily basis. KM can bring many benefits to an organisation if it is utilised properly. Organisations view knowledge as their most valuable and strategic resource Civi [21]. Organisations must strategically assess their knowledge resources and capabilities, and need to establish their knowledge strategy to sustain competitive advantages. Careful application of knowledge results in better decisions, particularly at the working level. These are not the decisions made by strategists at the top that make or break a company, but the sum total of the day-to-day decisions made at the front line of an organisation. Table 3.1 shows the advantages and disadvantages of KM in different parts of an organisation, looking at culture and behaviour Kuwan Aspinwall [51].

The next section we discuss the problems that are associated with KM and knowledge-sharing in organisations.

3.4 Knowledge Management Problems

Organisations do not know the KM tools available to them, the potential of these tools, and the challenges facing the organisations. Consequently, they cannot effectively choose from the variety of available tools. Furthermore, KM tools are often ill-suited for smaller organisations as they are primarily tailored for large organisations Davis [24]. We would agree with Davis statement as per the questionnaire which was conducted a section was completed by the organisations on what problems they were facing in regards to the KM all of the organisations has mentioned the complexity of the such systems were their biggest challenge and creating a learning culture in the organisation. In relation to the smaller organisations they has stated that the systems were too expensive for them to implement but had other methods of dealing with KM e.g. informal knowledge sharing within the department.

KM problems can be found through a KM analysis of a company, which can also identify the ways in which knowledge is created and disseminated. Small and large companies must recognise how employees go about accessing knowledge and acknowledge any barriers that they may face when trying to access knowledge.

Organisations need to uncover any internal aspects that may act as a barrier towards the implementation of a KM strategy. A fundamental weakness in many KM strategies is a failure to recognise the powerful internal forces such as culture, leadership style, values, structures and systems Cook [22].

It is stated by Little [55] that it is difficult for organisations to share knowledge efficiently and effectively and to be aware of the knowledge that they possess. Current KM technologies cannot yet handle the uncertainty of imperfect information. They cannot deliver the right information to the right person at the right time, because it is not possible to predict what the right information is and who are the right people to receive it. One of the main problems of KM is sharing knowledge in a multicultural environment. An example is given by McDermott [62], which discusses a study that was carried out with a number of companies where sharing knowledge was built into their culture. It was later discovered that the organisations did not change their culture to match their KM initiatives, and it became extremely difficult to share knowledge thus effecting overall performance. We can state that there are KM tools to share knowledge but some systems are too complex for the end user to use to the full extent according to the our questionnaire which was conducted among smaller and large organisations.

The next section we discusses knowledge sharing in organisations.

3.5 Knowledge-Sharing

Knowledge-sharing may be used to encourage the exchange and creation of knowledge in an organisation, that is, its brain power and intellectual capital, in order to increase its competitive advantage. In accordance to our questionnaire all of the organisations were involved in knowledge sharing in one form or another as it was a very crucial part of the KM process. Some companies used informal systems and other had KM tools to share knowledge.

Knowledge-sharing in organisations depends not only on technology, but is also related to behavioural factors. An overview is provided by Chun and Bontis [20] of the knowledge management field as it relates to expertise sharing and explaining why organisations don't know what they know. In Hinds [43], some of the cognitive and motivational factors that are thought to interfere with knowledge-sharing are discussed. This includes locked knowledge, e.g. an understanding of systems and programmes. It is vital that the correct knowledge gets to the right person at the right time, this is dependant on the culture of the organisation (the way of doing tasks). Knowledge-sharing can occur in meetings, through training or a conversation between employees talking about a specific topic Chun and Bontis [20].

The next section discusses the transfer of explicit and tacit knowledge.

3.6 Knowledge Transfer

This section considers tacit knowledge, although the research focuses on explicit knowledge. Any type of knowledge gathering can be difficult but Polanyi [69] states that the gathering of tacit knowledge can be particularly problematic. There can be problems associated with the conversion of tacit knowledge to explicit knowledge, which is generally very time-consuming Quintas and Lefrere [72].

Tacit knowledge transfer is dependent on its context; in order to be transferred effectively, tacit knowledge requires a higher degree of interpretation by the receiver Augier [7]. Just as individuals within an organisation may know a lot, they also hold different views and perceptions of this knowledge. When knowledge is transferred or created within an organisation, it is framed within the knowledge that is inherent in its routines that have been previously established Rollo [79]. It is the dynamic routines that allow the organisation to create and move forward with new knowledge while the static routines allow for building on established technology and knowledge by replicating it as required Rollo [79]. Externalisation is the term used by Hedlund and Nonaka [41] to describe taking internal or tacit knowledge and making it available to others by making it implicit.

The next section discusses the difference between tacit knowledge and explicit knowledge.

3.7 Tacit knowledge vs Explicit Knowledge

Tacit knowledge remains the most important form of knowledge for an organisation as it cannot be embodied in a code or a language and it cannot be communicated easily Chase [19]. Several factors affect the utilisation of tacit knowledge. There are internal factors, which are further categorised into different groups, such as memory, communication and motivational systems. Memory systems include experience, mental models and intuition, these are factors which function as constructs and manifestations of memory (tacit knowledge) of an individual employee.

This research focuses primarily on the explicit aspect of knowledge, that is the knowledge an individual knows, and on how it can be modelled. It touches on the tacit aspect of knowledge and compares it with the explicit part, by asking individuals what they know.

3.7.1 Tacit Knowledge

Tacit knowledge is a crucial input to the innovation process. The tacit aspects of knowledge are those that cannot be codified, but can only be transmitted through training or gained through personal experience Polanyi [69]. Tacit knowledge has been described as know-how, as opposed to know-what (facts) and know-why (science). It involves learning and developing skills but not in a way that can be written down.

3.7.2 Explicit Knowledge

Explicit knowledge is codified knowledge that can be transmitted in formal, systematic language. It is recorded historically in libraries, archives and databases, and is assessed on a sequential basis. Explicit knowledge can be expressed in words and numbers and shared in the form of data, scientific formulae, specifications and manuals Chase [19]. According to the questionnaires the results stated that all of the companies had documented information for training purposes and policies and manuals which are also written down to assist in knowledge management.

Explicit knowledge is communicated through interaction, language and proximity. When data is communicated, it is interpreted as knowledge. Organisations rely on knowledge brought into the organisation mostly by new employees, consultants, contractors and clients. Tacit and explicit knowledge resides not only in large organisations but also in SMEs. More attention needs to be given to SMEs to make them realise how they can better utilise their resources and information so that they can retain and reuse knowledge through knowing what their employees know. SMEs and large organisation have the potential to re-organise their structure and systems to effectively benefit from KM solutions Beijerse [8].

Our knowledge management framework concentrates on explicit knowledge and its formalisation. It demonstrates how epistemic logic can help to formalise and model knowledge, and codify natural language to formal language.

The next section discusses the knowledge management strategies in organisations.

3.8 Knowledge Management Strategy

Organisations recognise the strategic importance in managing knowledge through KM tools and identify the need to devise the correct KM strategy. Effective KM is a key concern for most organisations including small and large companies. SMEs and large organisations are looking for ways of introducing KM strategies into their companies, but first, they need to know the benefits of KM and understand how it can fit into their strategies and future planning. Organisations will remain competitive through managing their knowledge, by developing appropriate processes and infrastructure for capturing and creating relevant knowledge and disseminating it accurately, consistently, concisely and in a timely manner Zack [97].

Organisations that follow a KM strategy are more successful in managing knowledge, compared with companies who set out to manage this key strategic asset without a clear strategy Arora [5]. It is agreed by Bollinger and Smith [11] that organisations need to remember that a KM strategy should not be too complicated. It is correct to say that a KM strategy should be simple and user-friendly Bollinger and Smith [11]. This encourages and motivates employees to further engage themselves with the KM strategy. A good KM strategy should be natural and easy for employees and should not be difficult to implement or maintain. Employees are more likely to abandon a KM strategy that has too many rules and regulations Bollinger and Smith [11]. In accordance with the results from the questionnaire most of the organisations would like to have a strategy in place but the senior managers and owners of organisations do not think having a KM strategy was important.

Knowledge is a resource that is valuable to an organisation's ability to innovate and compete. Everyday essential knowledge walks out of the door and much of it never comes back. Employees leave, customers come and go and their knowledge leaves with them Chaffey [17]. The only way for an organisation to achieve a competitive advantage within the dynamic and changing environment in which it operates, is to find out what it knows, how it utilises what it knows and how quickly it can learn. Organisations need to develop and implement a KM strategy of some form to successfully manage this key strategic asset.

Organisations recognise the strategic importance of managing knowledge. Effective KM is a key concern to all organisations and are continuously are looking for ways of introducing KM strategies into their companies.

Below are some key objectives and basic guidelines for adapting to a KM strategy:

- Improve and encourage knowledge exploitation
- Improve knowledge access
- Improve the process of knowledge innovation
- Manage knowledge as an asset

In order to create a successful KM strategy, an organisation needs to recognise the link between its business strategy and its KM strategy. A KM strategy should be devised so that it focuses on the exploitation and creation of knowledge that will support the firm in achieving its strategic goals Zack [97].

A KM strategy should address the strategic gap of an organisation. The strategic gap represents the difference between what a firm must know and what it should do to be competitive, compared with what it actually knows and is doing Zack [97]. It should be noted that there is no "one size fits all" solution for devising and implementing a KM strategy. Dixon [26] has concluded by saying the method used by one organisation to leverage knowledge bears little resemblance to the methods that other organisations use, although they operate in similar ways.

3.9 Adaptive Framework

Our KM framework is adaptive to all organisations whether they are SMEs or large organisations. Our framework provides insight into what knowledge is flowing in the organisation as whole or a particular department, it then verifies the knowledge processes by using SPIN to confirm successful termination of KM process. If we compare our framework with Zack [97], we can see that this is only a static model which gives the organisations guidance on what procedures they should follow It does not involve any KM processes or any form of verification. An adaptive framework is shown in Figure 3.1 by Zack [97]. There is no universal solution for designing and implementing a KM strategy; organisations can follow and adopt any framework that will enable them to devise and implement a KM strategy according to their business needs Zack [97].

This thesis presents a KM framework, which is universal and applicable to all organisations. It extends on the adaptive framework of Figure 3.1 by providing insights into the flow of knowledge in an organisation and further verifies KM processes involved, this can further help to identify KM problems and identify their solutions Zack [97].

The adaptive framework presented in figure 3.1 allows us to analyse the different procedures involved in the three steps which are: The first step of the framework allows is to identify the problem in the organisation, this is done by feedback from customers and employees, once the problem is identified. In the second step, we propose a solution to the problem and then evaluate a KM strategy depending on the solution proposed. If we compare the adaptive KM model to our KM framework, we can see clearly that our framework extends further by being far more elaborated in terms of its functionality e.g. our framework can verify KM processes which allow the organisation to make a strategic decision.

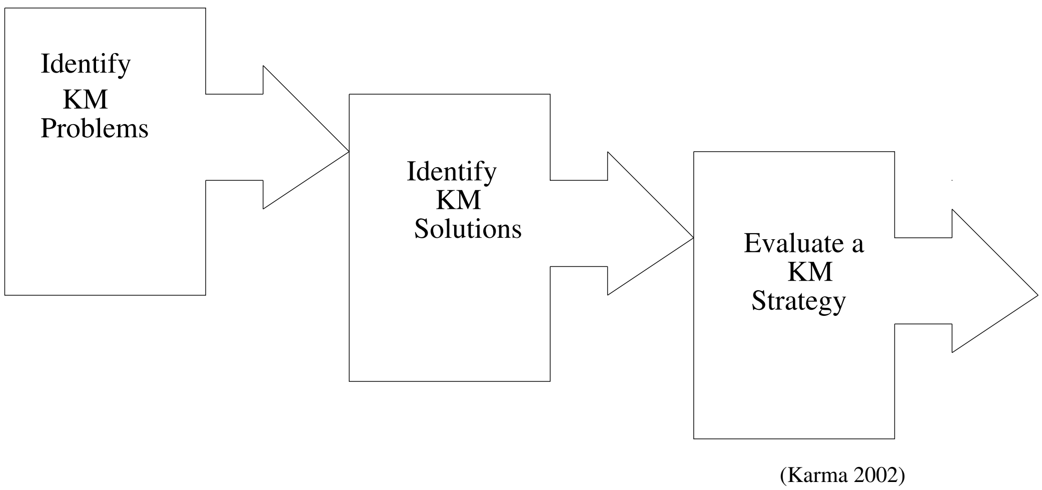


Figure 3.1: Adaptive Framework Model

We have discussed the motivational section which covered a wide range of factors relating to knowledge management and why organisations need to use KM to the problems of KM. We now discuss the background of the thesis, which involves how organisations perceive KM and give definitions of large organisations and SMEs. It also covers how KM can have an impact on the organisations and knowledge sharing.

Chapter 4

Background

Knowledge management is attracting attention Jennifer [48], but to a certain degree some of the literature is in agreement that there are few, if any demonstrations of any consequences of the adoption of knowledge management. It is argued by Jennifer [48] that knowledge has become the main competitive tool for many organisations. It has been described by Drucker [27] that knowledge rather than capital or labour are the only meaningful economic resource in the knowledge society. Our research focuses on identifying knowledge flow in an organisation and verifying the knowledge through SPIN model checker. Before one can talk about KM, it is useful to have an understanding of "What knowledge is?" Knowledge is defined by Drucker [27] as: "Information that changes something or somebody either by becoming grounds for actions or by making an individual or an institution capable of performing different actions." This definition addresses both the individual and corporate aspects of knowledge. Additionally it focuses on the desired goal of more effective action, i.e. competitive advantage and the perspective of knowledge as a goal-oriented enquiry-based activity. Knowledge is not just a collection of information Ackoff and Emery [2]. Organisations are increasingly aware of the importance of managing knowledge, like any other asset, in an attempt to gain competitive advantage. Yet, there is still disagreement as to the vision and definition of KM. Another description of KM is "the caring and sharing of knowledge" Toumi [90]. However, there needs to be more than just knowledge-sharing in an organisation before a company can benefit from KM, e.g. the company should analyse how knowledge is disseminated and organised and how it can be captured for future use Stenmark [86].

KM is only a perspective for implementing organisational change. It requires people to record knowledge, convert it to data and then share it. A good and simple definition of KM is that it is a fluid mix of contextual information, values, experiences and rules Nonaka and Teece [67]. This description includes explicit and tacit knowledge and experiences, not just data and information.

KM is a discipline that promotes an integrated approach to identifying, capturing, evaluating, retrieving and sharing all of an enterprise's information assets Ruggles [80]. In Ruggles [80] it is stated that all information should be shared; however, this can lead to irrelevant sharing of information among different departments, according to the questionnaires the companies were reluctant to share all of the information as they did not want to share sensitive information to their employees. There is no right or wrong definition of KM, as one may fit a specific company better than another. It can be argued that the above definitions are for organisations of different sizes and in different industry sectors. Nonaka [67] extends the description by stating that knowledge management can be used as a learning tool in all organisations, whether large or small, and as an aspiration. It is argued by Lee and Yang [52] that knowledge is data organised into meaningful patterns, information is transformed into knowledge when a person reads it and understands it and applies it.

According to Snowden [85], this is the beginning of KM and the change in thinking required from both academics and business is considerable. Snowden[85] presents heuristics to demonstrate the required changes in thinking for managing knowledge. We would agree with Snowden that we need to make more aware of KM in organisations especially smaller organisations as they require further information on what KM is and how this can effectively improve their business according to the questionnaires results

Knowledge cannot be forced from employees, it must be given freely Snowden [85]. We can disagree with this statement as knowledge can explicitly be derived from employees if we have the right tools and a learning environment. People always know more than they are able to tell, and are able to tell more than they can write down. It is correct to say that many employees know more than what they know and it is difficult for them to write down what they know on paper Snowden [85]. In the next section we will discuss the core themes of KM.

4.1 Core Themes for Knowledge Management

This section talks about the themes used for knowledge management and KM initiatives adopted by organisations and how these initiatives fail and what we can do to avoid this failure. This section also discusses how our KM framework can help to avoid such failures by analysing knowledge flow in the organisation Jennifer [48].

A study was conducted by the Delphi Consulting Group Inc, this included 36 vendors and more than 650 evaluators and users of knowledge. The purpose for the study was to see how many organisations use knowledge management and the results revealed that 28 percent were currently using some form of knowledge management and another 70 percent anticipated using it within four years of when the survey was conducted Jennifer [48]. It is stated by Davenport et al [56] there is an increase in organisations using knowledge management presently and in the future in the KM field but John and Elizabeth [49] states that it is all well that organisations are taking interest in KM initiatives and programmes but a large portion of KM initiatives fail, yet despite the restrictions to "learn from failure".

Little detailed attention has been paid to why and how these apparently popular initiatives run into difficulties. In John and Elizabeth [49], the paper aims to identify the key areas of failure and analyse what went wrong with the KM initiatives and to identify the key learning points we can compare this point to our results from the questionnaire as all of the organisations from SMEs to larger organisations the problem they face it the technical issues with such systems and failure to provide results also one of the problems was the complexity of the systems and how better we can train the employees in using them. Our proposed framework can identify the difficulties in the company by analysing the knowledge flow within the organisation and further verifying the processes through SPIN model checker. If we compare John and Elizabeth [49] key learning points which sets out to identify, we can conclude by thorough investigation, why the KM initiative project failed, this was due to the top management not fully being committed to a certain extent throughout the KM project and this caused the business conditions to deteriorate. One of the other factors was that the principles of the learning organisation were not instinctively realised as valuable or even reliable during a period of crisis. If our KM framework was applied to the Delphi Consulting Group, we would have been able to identify the issues of knowledge flow in the departments that were involved prior to the implementation of KM initiative and analysing the flow of knowledge and this would have allowed us to know who knew what in the department and what they needed to know to analyse the problems associated with the KM project.

The next section gives a definition of SMEs and large organisations. It then address, the importance of KM in small and large organisations and how companies perceive KM. This is followed by why small and large organisations need KM.

4.2 Definition of SMEs

Definition 4.2.1 *Small and Medium Enterprises (SMEs) are defined by the Small Business Service SBS. The statistics unit states that out of 4.7 million businesses in the UK, 99.3% are small firms with fewer than 50 employees and 0.6% are medium-sized firms with 50–249 employees (Small and Medium-Sized Enterprise Statistics for the UK and Regions 2007, published 30th July 2008). There is no single definition for a SME either nationally or internationally. One definition is that an SME has a turnover of not more than £6.5 million and a balance sheet totalling not more than £3.26 million and not more than 50 employees (Companies Act 2006), whereas a medium-sized company has a turnover of not more than £25.9 million a balance sheet total of not more than £12.9 million and not more than 250 employees (sections 382 and 465 of the Companies Act 2006). These definitions are not universally applied.*

In the next section, we compare large organisations and small organisations, as this provides an idea of how many agents are involved in our proposed framework. SMEs will have a lot less agents than the larger organisations, and less complex knowledge structure.

4.3 Small Organisation Structure

Small organisations have simple organisational structures, and are classified as independently owned or as partnerships. Small organisations do not have much of a hierarchy, with few levels of bureaucracy in the vertical direction. This means the top level is close to the operational functions.

Figure 4.1 shows two typical structures for SMEs. These can be found in most SMEs with a flat structure. Structure A has the most basic structure with an owner or manager, and sales personnel at the lower level. Structure B is an extended version of structure A. When a company adds to its products and services. It's structure grows as it employs new staff, including managers, e.g. by adding a supervisor to the hierarchy and explain the sales force to keep up with demand Jones et al [34].

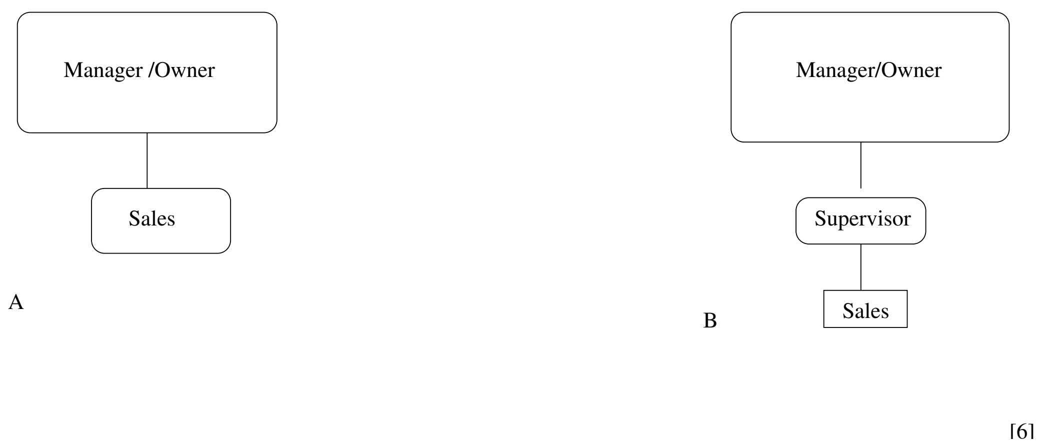


Figure 4.1: Structure of SMEs

SMEs have the financial capability to use KM initiatives, such as KM tools Jones et al [34] and they are able to implement a knowledge management database, which can be used to store knowledge. Managers or owners may be able to observe and acknowledge that KM can assist by collecting organisational data and utilising it effectively, and to help SMEs to make the right decisions based on the information collected. This can be done by changing the rules and regulations within the company so that employees use information effectively. SMEs are also able to recognise and understand relationships and patterns of information, turning it into usable accessible information and valuable knowledge, which may lead to strategic plans and forward thinking. Many SMEs carry out little or no strategic planning for their organisation e.g. newsagents and their proprietors are solely interested in running their businesses on a daily basis and do not have strategic plans for their companies future Jones et al [34].

The next section we compare large organisations and SMEs.

4.4 Large Organisation Structure

This section discusses large organisations and their structures. Large organisations have the resources and capital to invest in new technology and expand into new markets, ventures and partnerships, which only serve to make the parent organisation stronger Jones et al [34], e.g. Marks and Spencer's intelligent label project was part funded by the Department of Trade Industry (DTI). Scanner technology was developed in conjunction with Intelligent Ltd. These are just a few examples of how large organisations benefit from KM, as they are self-funded or funded by an external body.

There can be many different departments in a large organisation, for example:

1. Research and development

2. Marketing and sales
3. Manufacturing
4. Accounting
5. Materials management

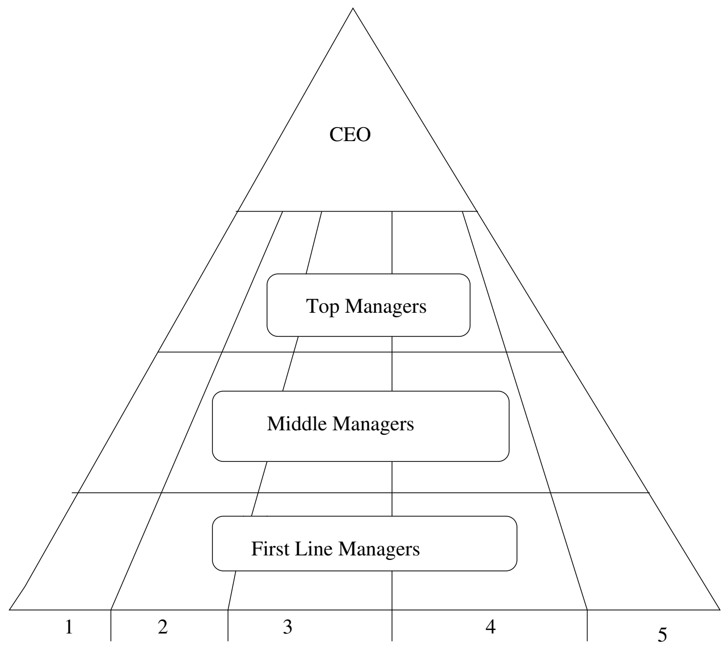
The structure is a formal system of tasks and reporting relationships that co-ordinate and motivate organisational members so they work together to achieve organisational goals effectively and efficiently. Figure 4.2 shows a hierarchy for a large organisation, where all managers work closely together to achieve goals and where the departments are closely related at all managerial levels. As a company grows and more employees are hired, the Chief Executive Officer (CEO) will realise that there is a need to create a hierarchy of managers Jones et al [34].

Senior managers are hired and the CEO becomes responsible for planning, identifying and selecting appropriate goals and courses of action.

Middle managers are hired and responsible for the effective management of organisational resources.

First line managers are hired and take on the day-to-day burden of leading and controlling human and other resources to help the organisation perform effectively.

Larger organisations have a much more complex structure. Organisational structures tend to be bureaucratic, which can make the organisation slower and less flexible in creating new schemes. Larger organisations have



Gareth et al (2000) [6]

Figure 4.2: A hierarchy of a large organisation

more resources to implement a new IT infrastructure, which gives them more expertise in implementing knowledge management. SMEs have an advantage because their structure is less complex Rasheed [73].

In the next section, we discuss the culture of KM in organisations.

4.5 Knowledge sharing culture

SMEs and large organisations tend to have a more organic structure and fluid culture than large organisations Rasheed [73]. A smaller number of people are employed, who are more likely to have common beliefs and values. This makes it easier for smaller organisations to amend and implement KM in comparison with large organisations. In smaller organisations, the culture can be predisposed by the owners. This can cause a problem if the owner does not trust his employees or does not encourage the culture of sharing and transferring knowledge. This can cause the owner to obstruct the development of knowledge management. It stated by Sharifuddin et al [47], culture is the main element considered in an organisation in relation to how information and knowledge is shared among the employees in the organisation. Knowledge sharing culture is known as one of the most important elements that need to be understood before implementing any KM strategies in organisations. The culture aspect is the key element as it determines the effects of various other variables such as technology and management techniques for successful KM Sharifuddin et al [47]. It is argued by Stoddart [87] that knowledge sharing can only work if the culture of the organisations promotes it.

In the next section, we will compare the management structures between SMEs and large organisations.

4.6 Management

Managers in SMEs and large organisations are sometimes the owners of the enterprise. In most cases, this implies that decision-making is centralised and there are fewer layers of management to deal with, whereas in larger organisations, the management structure can get quite complex and difficult to deal with. Rasheed [73] argues that SMEs have the advantage of being self drivers of KM and this simplifies the process of implementing KM. Another distinction is that the management of SMEs have to deal with every aspect of their business, which limits the time they have to focus on the strategic issues relating to KM, where as in large organisations, the senior managers have the power to delegate some of their responsibilities to lower management, which gives them more time to focus on KM.

The next section discusses the impact of knowledge management within SMEs and large organisations.

4.7 Impact of Knowledge Management

Knowledge management has multiple dimensions. It is viewed differently in different fields of activities. However, most organisations view knowledge management today, as a competitive and unique tool to stay profitable and to ensure the growth and development of their employees Masahudu [61]. organisations regard intellectual capital as an important asset and strive to deploy knowledge management in an organisation in order to gain a competitive edge. "Capturing knowledge buried in people and in organisations are the fundamental building blocks of knowledge management implementation" Masahudu [61]. The knowledge of an organisation is stored in the minds of its workforce. The workforce has to be motivated and empowered to contribute their best in fulfilling the mission and vision of the organisation, but they can only do this by having the right resources and the right level of knowledge available to them. Our KM framework builds on the information required for organisations and on core knowledge streams see chapter 6.1. . We use the framework to verify properties of knowledge. The director of knowledge systems Smith and Hansen [84] at Baby Well US West states that managing knowledge as an asset spawns whole new disciplines. It changes how executives think about economics, technology, human resources and planning. It can be argued that not all executives think alike Chase [19]. Codified knowledge can be written down and transferred easily to others, and in a knowledge-driven economy, it helps to improve the competitive advantage of a business. A stronger emphasis is given by Sirkantaiah [83] on the importance of knowledge management by stating: "Knowledge Management is the hot topic in the business world and many practitioners in different disciplines have become active partners in embracing in the KM field". "Capital consists of a great part of knowledge and organisation knowledge is our most powerful engine of production" Marshall [60].

Knowledge management is one of the biggest assets of every organisation Masahudu [61]. In order to sustain this invaluable asset, organisations must encourage employees to pass on the knowledge to others in the organisation but the knowledge should only be passed to the relevant person who requires it there also should be a level of security on what type of knowledge is being passed on. It is a process of requirements, transformation, and diffusion of knowledge throughout an enterprise so that it can be shared and thus reused. Masahudu [61]. The reuse of knowledge within an organisation is important that organisational management must encourage employees and team leaders to communicate effectively and clearly when diffusing knowledge to other members in their group. A side from extracting and clarifying knowledge from the individual, knowledge management programs must organise and provide structure to information so that it can be located and used effectively and convenientlyMasahudu [61].

When employees are knowledgeable, this gradually builds an idea or attitude in a persons mind and builds confidence, and a good sense of direction to guide and lead others this is the first step in individual growth and development. Management must encourage individuals to seek outside knowledge as well in a form of external training and seminars. This will help strengthen individuals knowledge and competency in order to sustain the organisation Masahudu [61].

In addition, management can manage knowledge to strengthen individuals and the organisation by promoting continuous education and change masahudu [61]. If management and the workforce can easily adapt or change to competition and needs of clients; it will be a greater opportunity for the organisation as well as the individual to learn and bring in new knowledge for the survival of the organisation. Commitment by both management and employees to continuous education opportunities is a foundation for an organisation to sustain and strengthen its workforce for the benefit of both Masahudu [61].

Furthermore, management can manage knowledge to sustain organisational competitiveness by empowering, motivating, and rewarding knowledge seeking employees and individuals. Seeking knowledge means individuals could be ready for change and uncertainty, and more importantly, they will be ready to handle complex and challenging organisational issues. These issues could be technical, customer service, managerial, strategic, to mention a few.

The next chapter discusses static and computational models of KM and how they are compared to our KM framework.

Chapter 5

Knowledge Management Models

This chapter discusses formal models of KM, which have been developed to assist organisations in better utilising KM Nonaka [66]. Our KM framework in chapter 6 is compared against the KM models proposed by Rodney and Sandra [78] and Robinson et al [4]. The different types of models categorise knowledge into discrete elements, e.g. Nonaka's [66] model, which is an attempt at giving a high-level conceptual representation of KM and essentially considers KM as a knowledge creation process. Different types of static KM models will be analysed e.g static KM models against computational models. Some models represent data, information and others analyse the flow of knowledge and some have the capability to store KM in data repositories.

Fernando [31] discusses the analysis of the new knowledge management guidelines to evaluate KM frameworks. The paper Fernando [31] discusses the new development of knowledge management model developed by the North- American consultants [32] and [63] associated with the knowledge life cycle. The KM framework Fernando [31] aims to help guide the organisations in selecting the right KM framework the framework helps to choose from countless KM models and frameworks.

The New Knowledge Management (TNKM) is the term to label a group of themes practises and models that emphasises the integration of knowledge by broadcasting, searching, teaching and sharing which was introduced by Fernando [31], this model was selected for its pragmatic tone and desirable applicability in organisations. The model presented in Fernando [31] distinguishes three types of knowledge which are, World 1 being knowledge is represented or encoded in objects and physical structures. World 2 knowledge refers to beliefs or belief pre- dispositions about the world, the beautiful (ethics) and the right (moral); deals with the mental world of knowledge. World 3 deals with autonomous world of mental objects, encompasses shareable linguistic formulations theories, morals and knowledge claims about the world being beautiful and the right.

The knowledge life cycle model depicted in 5.1 introduced by Fernando [31] envisage a decision executive cycle (DEC) and this is encouraged by a problem between an agents current state of objectives and the worlds state of affairs the agent is trying to manage. The cycle consists of 4 stages which consist of planning, acting, monitoring and evaluation. The stages involved seek to suppress the perceived problem. The planning part deals with the activity involving production and integration of knowledge meaning setting priorities, goals and objective, making forecasts and performing cost/benefit assessments, as well as reviewing or re-engineering a work process. The model generates a plan instantiation of World 3 Fernando [31]. Acting means carrying out the specific domain business process or any of its components. It involves utilising the plan along with World 2 and 3 knowledge, but it does not generate new knowledge. If we compare the knowledge life cycle model to our framework, we can establish that our framework has been extended. We identify the flow of knowledge in the organisation then verify the knowledge by using SPIN model checker. The knowledge life cycle model only supports other models in terms of identifying flaws in the implementation of KM models in organisations.

We will now analyse Hedlunds and Nonakas [41] knowledge management models

Nonaka's model, shown in Figure 5.2, attempts to illustrate a high-level conceptual representation of KM as a knowledge creation process, this knowledge is considered as consisting of tacit and explicit elements. The explicit and articulated knowledge are represented by writing, drawing, and computer programs. The model depicted in Figure 5.2 assumes that tacit knowledge can be transferred through a process of socialisation into tacit knowledge and tacit knowledge can become explicit knowledge through a process of externalisation (top two boxes). The model also assumes that explicit knowledge can be transferred into tacit knowledge through a process of internalisa-

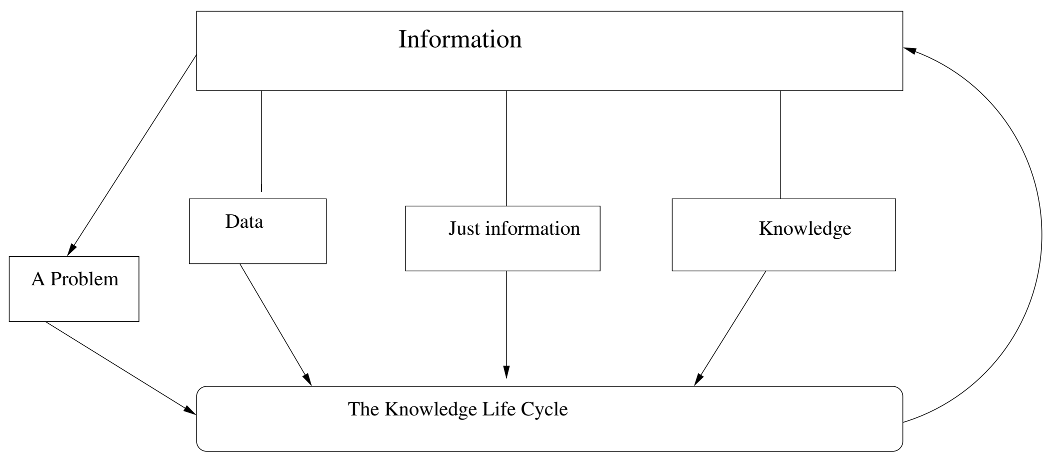


Figure 5.1: The knowledge life cycle model [31]

tion and that explicit knowledge can be transferred to explicit knowledge through a process called combination. This is illustrated in the lower two boxes of Figure 5.2. The transforming processes are assumed to be socialisation (everyday friendship), externalisation (forming a body of knowledge), internalisation (translating theory into practice) and combination (combining existing theories). The problem with this model is that it implies that it is easy to understand the flow of knowledge in an organisation, which is not the case as a knowledge flow is actually much more complicated and elaborate. Figure 5.2, as illustrated by Hedlund and Nonaka [41] is a different KM model to the one we propose as model is based on a high level representation. The proposed KM framework consists of knowledge management streams that allow modelling the flow of knowledge, these streams will then

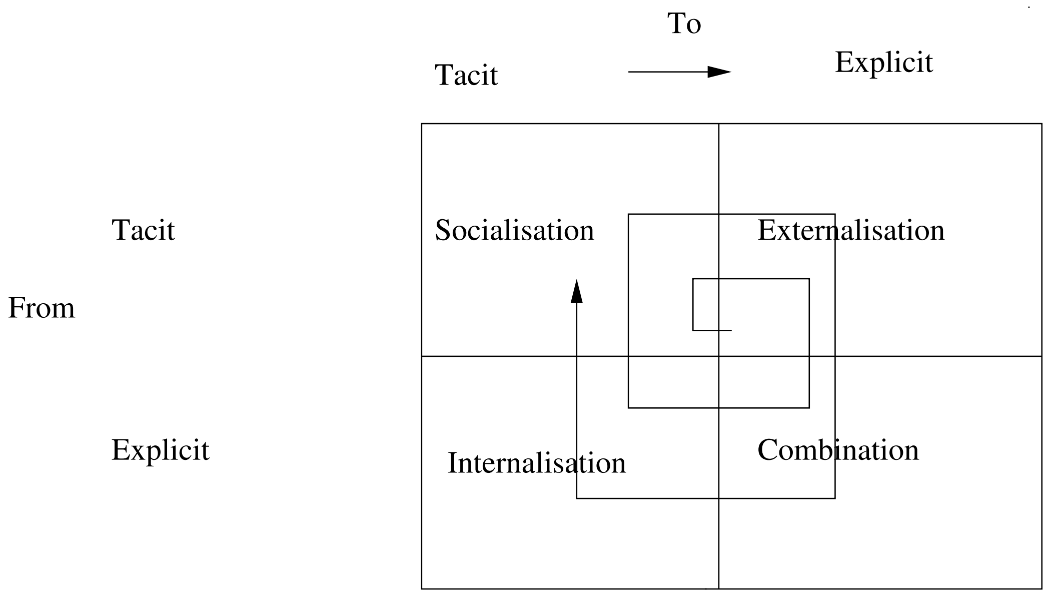


Figure 5.2: Hedlund and Nonaka's KM model [41]

be verified using the SPIN model checker Kuwan and Aspinwall [51]. Figure 5.3 shows an extended version of Hedlund and Nonaka's [41] model. This model assumes that there are four different levels of knowledge which agents are involved in an organisation these are: the individual, the small group, the organisation itself and the inter-organisational domain. This model is helpful in relation to our research as it provides an insight into the different knowledge processes in an organisation, split into different categories. Our KM framework is different in comparison to Hedlund and Nonaka [41] as we can use our KM framework to formalises the knowledge of an agent and analyse the movement of knowledge throughout the organisation using epistemic logic, and then verifies knowledge processes using SPIN. We will now look at various KM models and how they compare with each other.

	Individual	Group	Organisation	interorganisational Domain
Articulated Knowledge	Knowing calculus	Quality circles documented analysis of its performance	Organisation chart	Supplier's patents and documented practices
Tacit Knowledge	Cross cultural negotiation	Team Coordination completing work	Corporate culture	Customer's attitudes to products and expectations

Figure 5.3: Extended version of Nonaka's knowledge management model [41]

5.1 Demerest Knowledge Management Model

The model in Figure 5.4 views knowledge as being intrinsically linked to the social and learning processes within an organisation Demerest [25]. This model emphasises the construction of knowledge within an organisation. This construction is not limited to scientific inputs but includes the social construction of knowledge, which then becomes embodied within the organisation. This happens not just through explicit programmes but through social interchange. The solid arrows in Figure 5.4 show the primary flow direction while the plain arrows show the recursive flows. In comparison, the proposed KM framework provides an organisation with knowledge instruments, which the organisation can select. The appropriate streams for the business are then selected, checked and verified through the SPIN model checker.

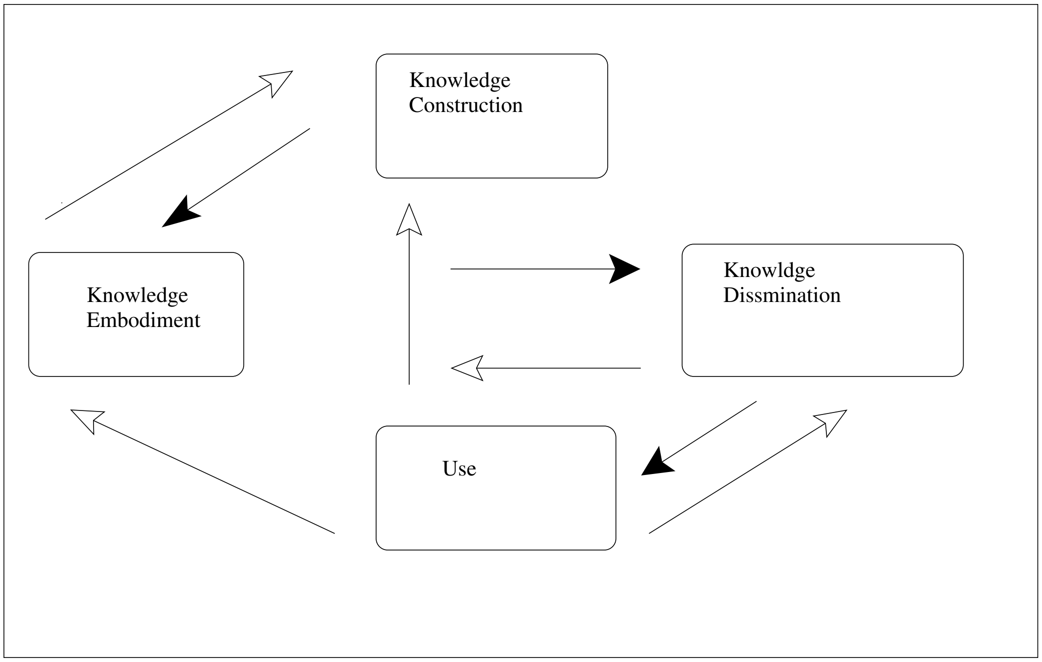


Figure 5.4: Demerest knowledge management model

5.2 Spiral Model

The spiral model, introduced by Nissen and Levitt [53] shown in Figure 5.5, describes a spiral of dynamic interaction between tacit and explicit knowledge along the epistemological axis (knowledge over time) and characterises four processes of socialisation, combination, externalisation and integration, which enables individuals knowledge to be amplified thus increasing organisational knowledge, shown along the ontological (flow time) axis. The socialisation states that members of team share experiences and perspectives. Externalisation states the use of metaphors through dialogue that leads to articulated tacit knowledge. Combination states co-ordination between different groups in the organisation including documented existing knowledge. Internalisation states diverse members in the organisation applying the combined knowledge from the four process stated above through trial and error and often translating the knowledge into tacit at the organisational level this is through work practises and routines. The term, stated learning by doing is used to describe the trigger for knowledge internalisation Nissen and Levitt [53] have built on these four theoretical steps as they integrate and extend the research to develop a model the flow knowledge by repeating the pattern shown in Figure 5.5 such interactions between triggers and conversion enables a continuous spiral of knowledge.

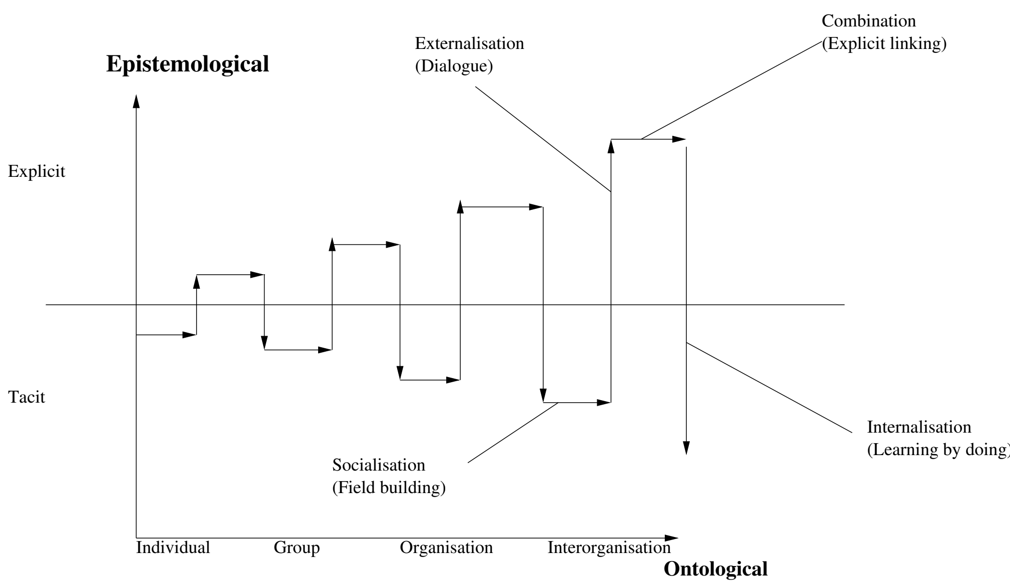


Figure 5.5: Spiral model [53]

The spiral model makes the flow in time explicit and it supports a multi-dimensional representational framework with a new approach to the analysis and visualisation of diverse knowledge flow patterns. The characterisation of knowledge flow dynamics remains static in terms of its representational model. Important dynamic interactions between model elements remain obscure because of the descriptive models based upon natural language texts and figures Demerset [25]. The proposed KM framework, in comparison, has a different purpose, that of capturing the properties of knowledge in an enterprise as well as understanding the flow of knowledge.

The spiral model helps to identify the knowledge flow over time and which category the type of knowledge is in e.g. explicit and tacit in an organisation, this model is different to our proposed KM framework. The spiral model does not use a formal language and it cannot be verified. The proposed KM framework will be verified using the SPIN model checker, this will verify the correctness and termination of the process.

We now discuss the VDT model (Visual Design Team) which deals with the static model and shows how information is processed throughout the organisation.

5.2.1 VDT Model

The Virtual Design Team (VDT) modelling environment has been developed by Mark and Raymond [58]. It takes an information processing view of organisations. The VDT research program (2002) demonstrated representational commitment and the qualitative behaviour of VDT computational models corresponds closely with enterprise processes when put into practice.

It embeds the software tools used to design organisations, by modelling, analysing and evaluating multiple virtual prototypes of the system designed on a computer, once formalised through a computational model Mark and Raymond [58].

The VDT model approach is different to that of our framework as it diverges from most existing research and offers a new insight into the dynamics of organisational behaviour by analysing the flow of knowledge. However, the VDT model has similar attributes to the our KM framework as it is also verified through the validation of the representation of a knowledge work process. This is done through simulation, but it is not designed to represent KM processes associated with the flow of knowledge through an enterprise.

Our study formalises specific processes associated with knowledge flow in organisations, as the organisations will be able to model their knowledge and understand the flow of knowledge, and how they can use KM to their advantage. This will help them to become more competitive in terms of offering better products and services, as the businesses know what they know. The study by Mark and Raymond [58] does not include any formalism in its framework, it only provides a list of necessary information that organisations need to follow in order to gain a competitive advantage in the marketplace.

The next section discusses the computational models and how they differentiate from static models.

5.3 Computational Models

In this section we, discuss the difference between computational models and static models and benefits of computational models. Our KM framework comprises of a computational model involving multi-agents interacting with each other. If we compare our framework with the computational models which are currently being presented, we can identify that our framework has the capacity of verifying processes by using SPIN model checker as other computational models which do not have the verification process linked to their models. There has been a increase in the use of computational models being used for understanding a specific phenomena e.g. understanding the behaviour of agents in an environment Ramchurn et al [82].

Computational models are based on agent-based modelling (ABM) or multi-agent simulation). This consists of simulating the actions and interactions of autonomous agents (both individual or collective entities such as organisations or groups) with a view to assessing their effects on the system as a whole, it combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming Ramchurn et al [82].

The models simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena. Individual agents are typically characterised as rational, presumed to be acting in what they perceive as their own interests. The computational models have been used in various industry sectors to draw conclusions Bonabeau [12].

Computational modelling is a powerful simulation modelling technique that has seen a number of applications including applications to real-world business problems Bonabeau [12]. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system they represent for e.g. producing, consuming, or selling. Repetitive competitive interactions between agents are a feature of agent-based modelling, which relies on the power of computers to explore dynamics. At the simplest level, an agent-based model consists of a system of agents and the relationships between them. Even a simple agent-based model can exhibit complex behaviour patterns and provide valuable information about the dynamics of the real-world system that it emulates. In addition, agents may be capable of evolving, allowing unanticipated behaviours to emerge. There are significant benefits to computational approach, i.e computational models are flexible in their ability to encode a wide range of behaviours between multi-agents.

We are able to analyse agent behaviour constraints that can be encoded and analysed. Computational models are also known to be rigorous in that conclusions follow from computer code that forces researchers to be explicit about assumptions. Computational modelling can be described as (i) Capturing emergent phenomena; (ii) Provides a natural description of a system; and (iii) Is flexible. The ability of computational models deal with emergent phenomena drives the other benefits and also captures the emergent phenomena Ramchurn et al [82]

In computational modelling we can model and simulate the behaviour of the system's agents and their interactions, capturing emergence when the simulation is run.

In such situations, computational models are defined as the positive expectation that an agent will act gently and cooperatively in situations Ramchurn et al [82]. The agents involved in the process have an important role to play. First, to help determine the most reliable interaction agent (i.e. those in which the agent has the highest trust), second, to influence the interaction process itself e.g. an agents negotiation stance may vary according to the opponents trust level, third, to define the set of issues that need to be settled in the scenario i.e. knowledge exchange or filling the knowledge gap. Generally interactions go through three main phases; (i) a negotiation dialogue during which the terms are agreed upon and agents assign an expected utility to that exchange (ii) an execution phase during which there are opportunities for the agent to defect, and (iii) an outcome evaluation phase where the client agent assesses the outcome of the task and finally derives some result Marsh [59]. If level of information or knowledge is sufficiently complicated, the agent is deemed reliable to handle the complexity of the scenario.

Less time can be spent looking for potential errors in the particular scenario, when there are only a few agents involved to derive the outcome which is expected. A number of computational models of trust have been developed. It is stated by Marsh [59] knowledge or fact is taken to be a value between agents and is calculated by taking into account the risk in the interaction and the possible outcome of an interaction. However, these concepts are not given any precise grounding and they do not take into account past experience and reputation values of the agent. e.g. computational models can be used in Sociology to symbolise trust between agents, in Sabater and Sierra [81] reputation symbolises trust and competence levels are gathered from the social network in which the agents are embedded. The main value of this model lies in showing how reputation can be used to guide an agents negotiation stance, but the evaluation of direct interactions is overly simple (disregarding utility loss and context) Ramchurn [82] adopts a probabilistic approach to modelling trust that takes into account past encounters as well as reputation information. However, it is not obvious how the model can concretely guide an agents decision making since the trust value is not associated to particular issues of the contracts that have been broken. In a more realistic setting, Witowski et al [6] develops an objective trust measure from an evaluation of past performance Witowski et al [6]. However, their approach overly simplifies the trust modelling problem and avoids reputation measures which could have enhanced the performance of their agents. Most models also neglect the fact that agents interact according to the norms and conventions determined by the society or environment within which they are situated Esteva et al [33].

The computational knowledge flow represents the knowledge flow process, in terms of software packages, which are the result of collaboration between people and computers the software packages are relatively pure form of knowledge processing. It is associated with processes and tools that have been the focus of information systems literature N.Duc [28]. The computational models are able to describe relevant behaviour, such as omniscience, which is defined as knowing or seeming to know everything, e.g. an agent may not be aware of a proposition and therefore does not know it. An example of a computational model is given in [3], which demonstrates the so-called DDL-system (distributio, doxa et logica), where personal cognitive modalities are placed at the intersection of meanings for internal and external subjects. The system is based on the language L of propositional modal logic and modal operator B of belief Adamatzky [3]. The system in this model computes the necessary action depending on the variables and parameters. In static representations of knowledge, there are no variables or parameters.

An agent may have limited logical capability and not know all the axioms and inference rules. It is also possible that the agent does not care about the consequences of a sentence, so does not even try to compute it. The most important part of non-omniscience is the agent's resource boundedness. Agents simply do not have enough computational capacity, in terms of time and memory, to compute all the consequences of their knowledge. In comparison, the proposed model avoids any kind of omniscience and computes all processes.

A strategy to solve the logical omniscience problem is to weaken epistemic logic. In a weak system, an agent only knows "obvious" logical truths but not complicated ones. From this, it is assumed that the agent can draw all "obvious" consequences, but not any illogical consequences. This is achieved by suggesting that the deduction mechanism of an agent is not complete, which means that it is not powerful enough to allow an agent to draw all the logical consequences of its knowledge. If an agent's inference level is kept weak then logical omniscience can be avoided.

We have discussed and compared different models of KM and how they compare to our framework. We will now propose our KM framework in two real case studies from the Journal of Knowledge Management, based on knowledge-sharing in a large IT organisation Brent and Vittal [13] and knowledge gap in an organisational (engineering department) Appelbaum et al [74]. In the next chapter we discuss our proposed framework of knowledge management how this is applied to organisations.

Chapter 6

Proposed Framework

In this chapter, we introduce our KM framework which allows for verification and simulation of knowledge in two real life case studies in chapter 7. We start by defining the terms which are used in our KM framework. We use the term KM streams to refer to knowledge processes and the terms instruments also known as questionnaires. The term agent processes which are related to the agents involved in the protocol scene, these are verified by using SPIN model checker which checks for deadlocks and termination. Our KM framework consists of step wise modelling which takes us through the steps involved to verification. The knowledge management streams are abstracted from Beijerse [8] which have been adapted as a part of the proposed framework. Part of our framework involves the formalisation of the knowledge streams using epistemic logic, such formalisations, using epistemic logic, were constructed by Rennie [75] and Girl [38] for distributed intelligence and multi-modal logic for inter-agent communications. Other work on the theoretical foundations of distributed intelligence focuses mainly on distributed epistemic systems Chandy and Mirsa [18] the research builds upon to model multi-agent communication.

The KM model presented by Beijerse [8] was used to analyse the most important knowledge management processes in companies, e.g. knowledge-sharing, knowledge gap, and knowledge lock. These are just a few that are mentioned here, there are nine knowledge processes in total, called knowledge management streams, see page 110. The proposed framework extends the streams and instruments, it will be used in the verification of KM processes for the real-life scenarios discussed in Chapter 7. We now explain what each step of our KM framework involves in Figure 6.1.

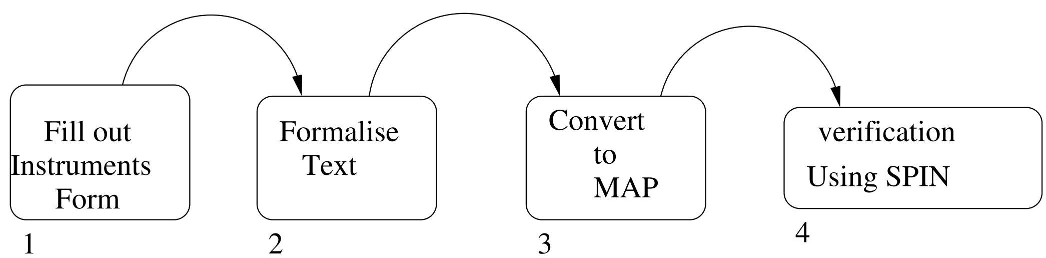


Figure 6.1: Knowledge management framework

The framework has the following steps:

- Step 1 uses knowledge instruments to evaluate which streams or knowledge processes are relevant for the case study. The company selects the questions, also known as instruments, that are applicable to them. Based on the instruments selected, the required knowledge management streams can be determined. Each stream has its own list of instruments, as shown on the stream management form adopted by Beijerse [8].

- Step 2 formalises the streams using epistemic logic. This allows the conversion of natural language to formal language using knowledge axioms, which are defined in Section 5.1.

- Step 3 converts the formalisation to the Multi-Agent Protocol (MAP) language and then to PROMELA, allowing for verification in step 4.

- Step 4 is the verification stage, which checks for safety, termination, fairness and correctness. It verifies knowledge properties using the SPIN model checker.

  Figures 6.2 and 6.3 show the instruments, also known as questionnaires this is the initial stage of our KM framework. These instruments are completed, allowing the determination of the streams that are to be modelled. Of the instruments introduced in [8], only those relevant to the framework have been used. The knowledge-sharing and knowledge gap streams are then formalised using epistemic logic.

  We will now discuss the knowledge management streams and how they relate to each other in Figure 6.4.

  The knowledge streams, from the second step of the framework, are shown in Figure 6.4. The streams are interlinked with each other forming the knowledge management streams, each box represents a knowledge stream and the black arrows show the flow of knowledge/information.

  The first stream is *Determine Knowledge Available* top left of the diagram at this stage the company determines what knowledge is needed. From this steam, there are links to *Knowledge-Sharing* and *Determine Knowledge Gap and Knowledge Lock*, which allows knowledge to be locked in place, these link to *Knowledge Utilisation and Evaluation.* The final step is the *Verification Process* using SPIN.

For example, an agent may require a critical piece of information, which is known by another agent. A knowledge request is made, which is acknowledged, and the second agent will then send the requested information to the first agent, as depicted by an arrow pointing from *Knowledge-Sharing* to *Determine Knowledge Available.* At this point, a manager will determine during *Determine Knowledge Available* whether the information is correct. If it is determined that the knowledge is correct, it will be verified by the *Verification Process* where the knowledge management stream process ends.

The next section discusses the streams involved in the framework we give examples of knowledge instruments known as questions which are used to determine the selected streams, this will be followed by giving an explanation of the streams involved.

6.1 Knowledge Management Streams

In the framework, seven crucial streams of knowledge management have been chosen, as these are the main streams used in organisations for knowledge processing. These streams can be applied to organisations ranging from SMEs to large organisations. The knowledge management streams in the

Knowledge Sharing Instruments	Found in Practice
Training by older employees having them work with younger employees	☐
Knowledge management system	☐
Job rotation	☒
Working in groups	☒
Information Technology for communication	☐
Use of databases	☐
Team Building	☒
The making of project fact sheets	☒
The central archiving of projects of which the results are accessible	☐
The facilitation of a consultation culture	☐
Tutoring	☐
Informal Information Sharing	☒

Figure 6.2: Knowledge-sharing instruments
[8]

Knowledge Gap Instruments	Found in Practice
Brain storming sessions	☒
Develop scenarios	☐
Performing meetings	☒
Performace appraisals	☐
Organising experience swap sessions	☐
Knowledge mapping	☒
Discussion with customer/clients	☐
Data bank C.V’s	☐
Meetings in groups and on one	☐
Training Plans	☒
Through knowledge information systems bases on information technology	☐

Figure 6.3: Knowledge gap instruments

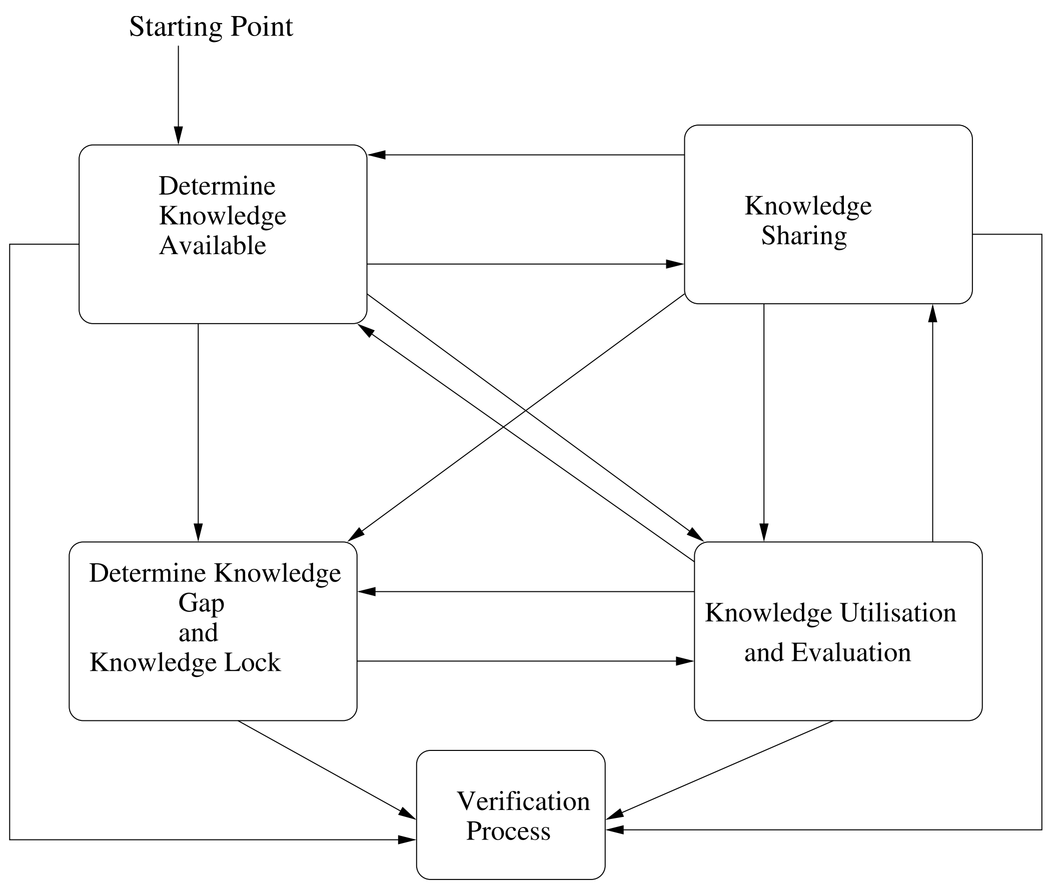


Figure 6.4: Knowledge Management Streams

framework are below, followed by instruments from Beijerse [8].

6.1.1 Acquired Knowledge

It is essential for any organisation to know what knowledge is necessary for it to meets its objectives. Organisations must remain competitive, e.g. by using better suppliers. Brainstorming sessions can help to determine what kind of knowledge is needed Beijerse [8].

6.1.2 Available Knowledge

This stream looks at what knowledge is already available in an organisation and how it can influence the company's strategy, for example through receiving information about suppliers or clients and through conducting in-house brain storming sessions.

6.1.3 Determine Knowledge Gap

The difference between what is currently known and what needs to be known is called the knowledge gap. For example, employees in organisations can complete their objectives when current knowledge equals target knowledge. The gap can be closed by training, which increases current knowledge, until employees know everything they need to know.

6.1.4 Knowledge Lock

When knowledge is locked in, it means that it has been stored within the organisation. This knowledge may have been found internally or purchased from external sources. It can then be accessed with appropriate restrictions.

6.1.5 Knowledge Sharing

Knowledge is a very important resource for preserving valuable traditions, developing new ideas, solving problems, creating core competences and initiating new opportunities for both individuals and organisations. Knowledge-sharing may encourage knowledge exchange and creation in an organisation. Knowledge-sharing in organisations depends not only technology, but also behavioural factors. In this research, the behaviour of the agents will not be considered, only their knowledge will be discussed.

6.1.6 Knowledge Utilisation

The utilisation of knowledge is largely down to the culture of the organisation and how management motivates its staff to utilise knowledge.

6.1.7 Evaluate Knowledge

Evaluation is required to find out what knowledge is retained, how it is utilised, its availability and its necessity. Organisations can evaluate their knowledge in various ways, e.g. through audits, satisfaction studies and benchmarking.

The next section explains how streams are formalised using epistemic logic.

6.2 Formalisation of Knowledge Management Streams and processes

This section discusses the language used for formalisation, lists the rules and standard axioms we use and model check the processes in MAP. It discusses the PROMELA language used for verification. It shows how we use epistemic logic to formalise the knowledge management streams.

Epistemic logic is used for the formalisation, with recognition expressions as "knows that" or "believes that". In addition to its relevance for traditional philosophical problems, epistemic logic has many applications in computer science such as cryptography, network security and robotics, and in economics Brown [14].

Among the approaches to epistemic logic that have been proposed, the modal approach has been the most widely used for modelling knowledge. An important reason for the popularity of this approach is its simplicity: systems of modal logic are given an epistemic interpretation. The main technical results of epistemic logic can be obtained almost automatically. To interpret modal logic epistemically one reads modal formulae as epistemic statements expressing the attitude of certain agents towards certain sentences, and the semantics for modal logic is also given a new interpretation Jospeh and Halpern [50].

The basic modal operator of epistemic logic, usually written K, can be read as "it is known that" or "it is epistemically necessary that", or "it is not inconsistent with what is known". If there is more than one agent whose knowledge is to be represented, subscripts are attached to the operator (K_1, K_2, etc.). So K_i α can be read as "Agent i knows α." Joseph and Halpern [50].

A rational agent in a multi-agent world needs to be able to reason about the world and what holds true as well as about its own cognitive state and that of the other agents. This involves statements that inevitably make reasonable assertions about beliefs, knowledge and other attitudes. Such statements may require quantification over the objects of the propositional attitudes or that such objects be denoted by terms. Moreover, an agent may have to refer to itself in a number of contexts either directly or indirectly Fasli [30].

Specific axioms and their instances for the knowledge streams have been selected, as they provide insight into the properties of the individual knowers; this provides the means to model complicated scenarios involving groups of knowers using epistemic logic. The process of acquiring knowledge is related to the use of reasoning, intuition and perception of modalities at the intersection of the meanings of internal and external subjects, making them work together with the meanings of neighbouring subjects. The system is based on the language L, which includes propositional modal logic and the modal operator K of knowledge Adamatzky [3]. The syntax and semantics of the language L includes propositional variables from $P = pi : i \in i$. The family $K_i i \in I$, where index i represents the name of the agent, and modal operators are used to distribute knowledge Adamatzky [3].

Rule K5 shows that knowledge is closed under implication. Contrary to epistemic systems, the proposed model does not use the axiom $K_i\ P \rightarrow P$ because an agent can believe P when P is false (whereas in the case of rational cognition, knowledge contains only true facts). This actually agrees with common sense where knowledge means the acceptance of something as true, even without it being completely guaranteed. Rule K4 represents reflexivity of knowledge because an agent knows what it knows. See page 33 for a list of standard axioms.

The belief axioms will be replaced by knowledge axioms by introducing the knowledge of individual knowers. This is possible because epistemic logic is used and deals with belief and knowledge. The research paper presented by Adamatzky [3] deals with non-logical axioms from propositional multi-agent doxastic logic, which is modal logic, concerned with reasoning about logic over time. In doxastic logic, if an agent knows a fact then the fact can change over time and the agent's belief also evolves over time. This research uses epistemic modal logic axioms, which are related to knowledge only and discusses how the knowledge of a single agent knowing only true facts changes when multi-agents are introduced.

We have discussed the steps involved in our KM framework and how the knowledge streams which we formalise. We will now make the transition from epistemic logic to MAP language as it shows the protocol in detail.

6.3 Model Checking in MAP and SPIN

The initial step in the application of the SPIN is the construction of the knowledge-sharing protocol system model. In order to generate the appropriate model for knowledge-sharing MAP protocols, a translation is performed from MAP to PROMELA. There are a number of similarities between these languages, e.g. both are based on the notion of asynchronous sequential processes, and for agents, both assume that communication is performed through message passing or exchange of information.

It is stated by Adamatzky [3] that there are three points of semantic mismatch between MAP and PROMELA. The first one concerns the order of execution of the statements. The MAP language makes use of unification for the invocation of decision procedures, for recursion and in message passing, while PROMELA has call-by value semantics. MAP assumes that messages can be retrieved in an arbitrary order (by unification), while PROMELA enforces a strict queue of messages. As stated before, the MAP execution tree cannot be represented in PROMELA as the language does not permit the definition of complex structures.

The next section discusses the conversion from the MAP protocol as this will allow checking of the properties, safety and termination of the process in PROMELA. For further information on MAP see page 35.

6.4 Conversion to MAP

The connectives used in both languages are also similar to epistemic logic. Both knowledge and belief can be expressed in these, for e.g. the communication concepts have the same style, and the semantics of both are based on an underlying theory of speech acts. These protocols or agents perform communication by passing of facts, α or β, between agents in the form of messages. The semantics of epistemic logic and MAP will now be compared.

Lemma 6.4.1 *The semantics of some epistemic logic constructs can be expressed in MAP as follows:*

1. $\mathcal{K}_i\ \alpha$, which states agent i knows a fact, is translated into MAP as $<$ inform $i\ \alpha >$.

2. $\mathcal{K}_i\ \alpha \rightarrow \mathcal{K}_j\ \alpha$ states agent i knows a fact and agent j also knows the fact. In MAP this is $< i\ \alpha$ inform $j\ \alpha >$.

3. $\mathcal{K}_i\ \alpha \wedge \mathcal{K}_j\ \beta$ states agent i knows fact α and agent j knows fact β. In MAP this is $< i$ inform α and j inform $\beta >$.

4. $\mathcal{K}_i\ \alpha \vee \mathcal{K}_j\ \beta$ states agent i knows fact α or agent j knows a fact β. In MAP this is $< i$ inform α or j inform $\beta >$.

5. $\neg\ \mathcal{K}_i\ \alpha$ states agent i does not know fact α. In MAP it is translated as $<$ not i inform $\alpha >$.

In the next section, we discuss MAP encoding and theorem.

1. *method (inform, $p, $i, $j) =*
2. *knows ($i, $p) then*
3. *not (knows ($i, kif ($j, $p)) then*
4. *not (knows ($i, uif ($j, $p)) then*
5. *inform (p) => agent ($j,_) then*
6. *assert (knows, $j, $p)*

Figure 6.5: MAP encoding for knowledge-sharing

6.5 Encoding of Knowledge-sharing in MAP

Figure 6.5 illustrates MAP encoding. Line 1 defines the method, which is a sequence of statements to perform for an action. For example, agent i, the sender, will *inform* the receiver, agent j, of a proposition p. Line 2 states that agent i knows the proposition. Line 3 states that agent i knowing the proposition does not mean that j knows it. Line 4 states that agent i is uncertain of j knowing the proposition then Line 5 informs j of the proposition, which implies the message has been transmitted to j. Line 6 asserts that j now knows the proposition. We are able to apply the same concept of encoding to knowledge gap.

Theorem 6.5.1 *Knowledge-sharing can be encoded in MAP.*

We have discussed the knowledge of properties and the formalisation process of streams. We have also discussed the conversion from MAP and to promela language for verification process. We have created a lemma to prove that it is possible to convert from MAP to promela. In the next chapter, we apply our KM framework to two real-life case studies and show how knowledge processes can be verified using SPIN.

Chapter 7

Case Studies

In this thesis we have selected two specific real life case studies do demonstrate our knowledge management framework, these case studies were selected due to their nature of business which involve communication between employees this includes knowledge sharing and knowledge gap being identified by using our Km framework it also identifies the problems in the companies we have selected. Our aim is to apply our KM framework to these real life case studies and simulate and prove properties of knowledge processes the benefits of our KM framework will allow the company analyse the flow of knowledge by simulating the knowledge processes and for verification of their correctness with respect to predefined process goals this is achieved by formal logical specification of the assumptions and knowledge management goals for each process. two case studies are selected which are knowledge sharing and knowledge gap We will be applying our KM framework which will involves 4 steps towards proving.

The case studies we will be applying to our framework will be knowledge-sharing Gunasekaren [88] and knowledge gap Appelbaum et al [74] and are especially suitable for modelling KM streams. The structure of the chapter is as follows: first it gives an introduction to the real-life case studies Gunasekaren [88] and their background. Next is the stepwise modelling of the verification procedure for KM processes. See Figure 6.1 in Chapter 6.

The knowledge axioms are specifically selected to model the flow of knowledge in the framework. The axioms are derived from the rules and schema's of a conventional epistemic system. The system is used to define the distribution, doxa et logica (DDL), which deals with personal cognitive modalities that are placed at the intersection of meanings of internal and external subjects, making them interact with each other based on the language L of propositional modal logic. The framework uses the same principles as the axioms of belief as these are transferable to model knowledge agents, since the laws of axioms allow model knowledge transfer. Refer to Adamatzky [3] for the language of epistemic logic and axiom rules.

The next section demonstrates the first case study which is knowledge sharing then followed by the knowledge gap case study.

7.1 Background for Knowledge Sharing Case Study

The knowledge sharing case study is based on a real-life scenario from the Journal of Knowledge Management, called "The applications of knowledge management in call centres", published in 2005 Gunasekaren [88]. The article presents various issues in knowledge management, amongst which is knowledge-sharing.

This research was conducted at Dixons Contact Centre (DCC) in Sheffield, South Yorkshire, UK. DCC belongs to Dixons Stores Group (DSG), which consists of Dixons Ltd, Currys Ltd, PC World Ltd and The Link Ltd. DSG is the number one retailer of electronic goods in Europe, with operations in more than 25 countries worldwide. The Dixons Stores Group was established in 1969 by Charles Kalms as a photo studio in London and during the late 1970s it diversified into electronic goods.

DCC offers a variety of call centre services. It employs approximately 1,200 trained customer service advisers (CSAs) to handle incoming as well as outgoing calls. It takes on additional temporary staff during peak call times. The case study Gunasekaren [88] gives insights into the functioning of a call centre and shows the creation, acquisition and sharing of knowledge among call centre agents.

KM and research initiatives have been implemented in a wide range of organisations sectors such as manufacturing, consulting, software, banking and insurance Davenport and Prusack [23]. According Gunasekaren [88] call centres, management effort is currently aimed at achieving information management. Call centre operations are especially suited to information delivery. What passes between the caller and the agent is information. Customer service representatives are expected to locate and process information quickly so that customer queries can be handled expeditiously Gunasekaren [88]. Information and communication technology (ICT) is an integral part of all call centres.

Call centres are centralised, specialised operations for both inbound and outbound communication handling. A call centre is a dedicated operation in which computer-utilising employees receive inbound or make outbound telephone calls, with those calls processed by an automatic call distribution (ACD) system. In DCC, its customers are provided with sales, after sales and technical support services. The work is automatically allocated to telephone operators to minimise waiting time and increase the speed of service. The level of downtime can be continuously measured and the quality of the interaction between the service provider and the customer can be assessed remotely and at management's discretion Gunasekaren [88].

A participant observer studied the daily activities of agents and observed the routine and non-routine situations, gaining exceptional insights that would not have been possible even through informal interviews. Interviews will also be used to determine the origin and flow of information and acquisition of knowledge, since tacit knowledge is not easily transformed into explicit knowledge for codification [88]. A participant observer also participates in unofficial activities, gaining insights into the informal channels of information sharing. These insights may not have been gained in a formal interview. Formal interviews with the staff will help to evaluate the effectiveness of the official channels of knowledge communication and identify possible shortcomings and areas of improvement in the information-sharing activities and, especially, in ICT systems.

The study was conducted in the after-sales services department, which deals with issues such as branch locations and telephone numbers, product details, stock availability, prices, special deals and discounts, complaints, replacements, product returns procedures, refund of money, and financial and credit queries Gunasekaren [88]. There are approximately 150 advisers in the various sections of the department, working full-time and part-time. Every agent has a computer with e-mail and other applications, a head-set for talking to customers, a box containing files and a locker.

Every partitioned area has an overhead television on which constant messages regarding work appear. Electronic boards are situated overhead at each end and in the middle of the hall, providing information about the number of workers available, the number of calls being attended to and the number of calls in the queue.

Explicit and tacit knowledge in this case study Gunasekaren [88] are now defined; general definitions of explicit and tacit knowledge are given in Section 3.7.

7.1.1 Explicit Knowledge in a Call Centre

Explicit and tacit knowledge were discussed in Section 3.7. This section shows how the employees use this knowledge in practice. Explicit knowledge is articulated and stored in the printed and electronic media in the organisation. Providing quality customer services requires the CSAs to have a good explicit knowledge not only of products and services, but also of procedures, rules and regulations for sales and after-sales, including the Data Protection Act and consumers' legal rights.

One CSA said: "even after working for six to eight months, we still receive many calls that are entirely new in nature and require me to learn something new".

This statement captures the opinion of most CSAs. Since the calls are so vivid and dynamic in nature, every CSA, especially in the first six to eight months, acquires, learns and develops a unique knowledge base that varies from other CSAs. This knowledge was gained from training manuals, computer systems, procedure manuals, company rules and regulations, personal notes, photocopies, etc.

In DCC, the CSAs utilise the information to serve customers, converting information into knowledge by their actions. The CSAs interpret the information to match the requirements of the situation and their action is the result of their interpretation. This real situation mimics the suggestion by Davenport et al [56] that knowledge is derived from information as information derives from data. Through repetition, the CSAs internalise this knowledge and discover faster and more efficient ways of serving customers, resulting in improvised knowledge Vladimirou and Tsoukas [91]. The CSAs not only memorise the location of the information, but also create short cuts and personal notes for future use. In DCC, most CSAs rely heavily on their personal notes, photocopies, leaflets, etc as well as using the formal information system provided by the company.

CSAs share information informally, with other team members, during breaks and other leisure activities. This informal information sharing does not involve the team leaders and ultimately goes unnoticed by management. If there were ways of sharing this knowledge in a formal way, it would be possible to speed up the learning process in the organisation to achieve quality customer service in a shorter time. Management may be unaware of many problems that exist in the operations, sales and after-sales functions.

7.1.2 Discussion

In the case study Gunasekaren [88], a KM model was developed to aid the organisation in managing knowledge and information. The model is based on Davenport [91], which was developed for a call centre.

The model in Figure 7.1 shows that at the core of the KM process is personal knowledge, classified as tacit, explicit or cultural. There are various roles associated with knowledge and KM is achieved by identifying and managing these roles efficiently. We can compare Figure 7.1 against our framework. The main difference is the model depicted is a static model

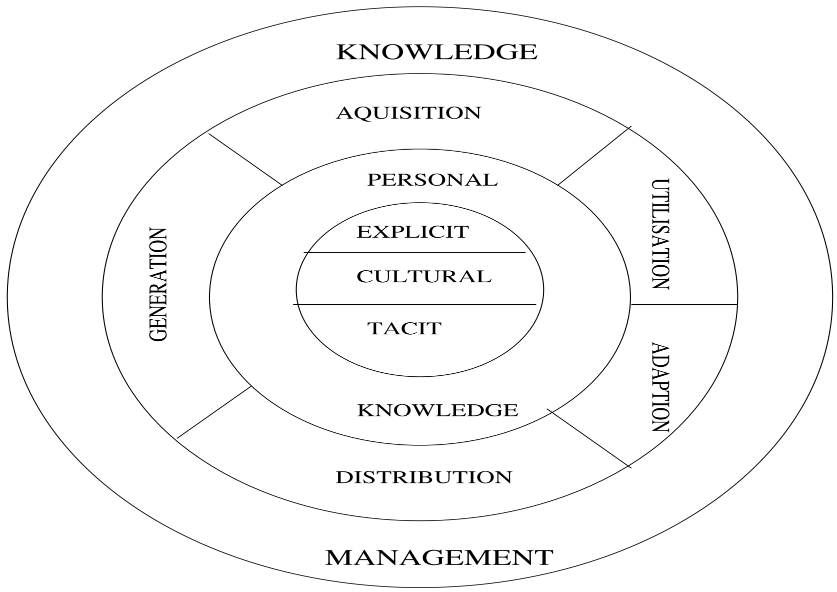


Figure 7.1: Knowledge management model for call centres

which give organisations an overview of how knowledge is represented as a whole and how shows how knowledge is distributed. Our KM framework is very dynamic and it analyses the knowledge flow in the organisation or in a department then verifies the processes involved e.g. agents involved in a dialogue. A brief examination of how these roles work in an organisation is needed in order to appreciate their importance and nature and to understand how organisations can be managed Figure 7.1 is explained below:

7.1.3 Knowledge Acquisition

Knowledge is acquired in various ways. For example, the induction programme for new employees in the case study. The new recruits already possess knowledge acquired from external sources, such as educational institutions, previous employers, etc. This knowledge, which the recruits bring with them, may be directly relevant to the organisation and can be used to the organisation's benefit, e.g. previous customer service experience. Information contained in ICT, manuals, memos, e-mails, etc. provides a supporting environment to enhance this acquisition processes. There are no limits to the sources of knowledge. Knowledge acquisition also involves storing this knowledge in a convenient format for future retrieval. However, the conversion of tacit into explicit knowledge has its limitations, because tacit knowledge can only be shared to a limited extent Gunasekaren [88].

7.1.4 Knowledge Utilisation

The ultimate purpose of knowledge is that it is used in an organisation. In DCC, the utilisation takes place when knowledge is put into action by CSAs during a customer query, or it is utilised by team leaders to manage CSAs, or utilised by management for decision-making or policy-making. Knowledge utilisation results in knowledge increase, through expertise and insights. A CSA learns through experience on how to deal with a particular type of enquiry efficiently. First, frequent use of a piece of information helps an employee to locate it faster, because they remember where to find it. Second, an experienced CSA will anticipate a customer's reaction, and is able to respond accordingly. CSAs devise their own methods of dealing with customers using trial and error. Knowledge is useless if it is not utilised. People do not just passively receive knowledge; rather they actively interpret it to fit with their own situation and perspective Nonaka [66]. Utilisation of knowledge increases the expertise in a domain of action, and the user becomes an expert through repetition.

7.1.5 Knowledge Adaptation

Knowledge may lead to changed behaviour, for example, CSAs modify their action with experience. CSAs have to follow certain procedures while dealing with issues and complaints. The CSAs get this information from the complaints procedure manual. They have to interpret any situation and adapt the rules to respond according to the scenario.

7.1.6 Knowledge Distribution

When knowledge is shared in an organisation, in order to achieve an organisational goal, it becomes distributed. Sharing of knowledge can be formal or informal. Formal sharing takes place through official channels like meetings, discussions, e-mail, web-postings, memos, etc. Informal sharing takes place inside or outside the office during breaks, etc. Deliberate management attempts can improve knowledge-sharing, such as through using community of practice, quality circles, buddy training, etc.

7.1.7 Knowledge Generation

Knowledge generation is closely interrelated to the other roles. Knowledge generation draws extensively from the existing knowledge base, e.g. transformation of explicit, tacit and cultural knowledge to new knowledge. The solution of issues results in the generation of new knowledge. To find a solution, a problem needs to be studied thoroughly. Once a solution has been found and implemented successfully, the new knowledge can be made available throughout the organisation. Such practises enable a continual shift in the culture of an organisation, as new knowledge becomes diffused.

7.1.8 Definition of the Problem

It has been noticed that CSAs and other employees in the same team share information informally during breaks and other leisure activities. Informal information sharing does not involve team leaders and ultimately goes unnoticed at the management level. If there were ways of sharing this knowledge in a formal way, it would be possible to speed up the learning process in the organisation to achieve quality customer service in a shorter time. Employees may be unaware of problems that exist in other departments.

The next section discusses a series of modelling steps, which allows simulation of the knowledge-sharing processes and checking of the relevant properties associated with the streams.

7.1.9 Stepwise Modelling

The framework relies on the identification of processes, which supports knowledge management. These are expressed in the formal language of epistemic logic. Multi-agent dialogues are translated into a protocol language, which is model checked to detect inconsistencies such as non-termination and unfairness.

The four steps steps of the proposed KM framework will be discussed individually. Normally, companies would be asked to fill out questionnaires, in our case we have already established the knowledge problem within the knowledge sharing and knowledge gap case studies as this covers the first modelling step which is selecting the instruments.

7.1.10 Step 1 – Selection of Streams

In step one, the company selects instruments that are specifically designed to determine which knowledge management process is to be modelled, e.g. this identifies the activities that take place in the company: working in groups, job rotation, team-building or project fact sheets. All of these fit under the knowledge-sharing stream, as in Figure 6.2, Section 6.1, and are abstracted from [8].

7.1.11 Step 2 – Formalisation Process

Step two involves formalising text using epistemic logic. This is demonstrated by describing how axioms are used and read. In this context, the formalisation has two agents, i and j, corresponding to the team leader and employee.

These are the standard rules of axioms, which are applied from Adamatzky [3].

The formalisation starts with an initial state, where the two agents know a fact, and finishes after an exchange of information, so that they now know what they did not know before. This will entail both agents sharing some information. The formalisation is split into three sections. The first section describes how many agents are involved and what they already know. In the second section, the agents exchange information. The final section concludes the formalisation after the information has been exchanged successfully. The formalisation uses the knowledge law axioms.

The knowledge-sharing stream is next formalised using the language of epistemic logic. There will be two agents involved in the knowledge-sharing process, who exchange information.

Formalisation of Knowledge-sharing

Initial state

- K_i α – Agent i knows fact α, the fact could be from data worksheets, which contain historical data about the company.

- K_j β – Agent j knows β. This fact could be from customer feedback forms.

α and β are facts or information.

Process

- $K_i\ \alpha \rightarrow K_i\ K_i\ \alpha$ – instance of (K4). Agent i knows α, which implies he knows that he knows α.

- $K_j\ \beta \rightarrow K_j\ K_j\ \beta$ – instance of (K4). Agent j knows β, which implies he knows that he knows β.

- $\neg\ K_i\ \beta \rightarrow K_i\ \neg\ \beta$ – instance of (K3). It is not the case agent i knows β, which implies agent i knows not β.

- $\neg\ K_j\ \alpha \rightarrow K_j\ \neg\ \alpha$ – instance of (K3). It is not the case agent j knows α, which implies agent i knows not α.

- $\neg\ K_i\ \neg\ \beta \rightarrow K_i\ \beta$ – instance of (K2). It is not the case agent i does not know β, which implies agent i knows β.

- $\neg\ K_j\ \neg\ \alpha \rightarrow K_j\ \alpha$ – instance of (K2). It is not the case agent j does not know α, which implies agent j knows α.

End state

- $K_i\ (\alpha \wedge \beta) \rightarrow K_i\ \alpha \wedge K_i\ \beta$ – instance of (K6). Agent i knows both facts α and β, which implies agent i knows fact α and agent i also knows fact β.

The outcome of the knowledge-sharing process, shown in instance (K6), is that agent i and agent j have exchanged information, which they did not know before. This is a formalisation of the knowledge-sharing process.

7.1.12 Step 3 – Conversion to MAP Knowledge-sharing

The formalised stream is converted to MAP then to PROMELA for model checking. The protocol in Figure 7.2 shows a knowledge-sharing-based description of the protocol between two agents, the team leader and the employee. Knowledge-sharing begins with an initial state where both agents know what they know.

The agents share information with each other, as shown in Figure 7.2. The employee enters a state in which a decision is required and the team leader can accept or reject sharing the knowledge. The employee also has the choice of rejecting or accepting sharing the information. If sharing is rejected, the process will end, but if sharing is accepted, the information is communicated to the team leader, and the employee knows that the sharing has successfully taken place and the protocol terminates.

Knowledge sharing protocol scene in MAP

The knowledge-sharing protocol shown in Figure 7.2 effectively captures the knowledge movement through the sequence of interactions between the team leader and employee. The variable names of the role names are prefixed by %. There are two roles: the %`team leader` who is the sharer of the knowledge, and the %`employee` who will be the receiver of the knowledge from the team leader. We will now explain how the protocol works. The knowledge sharing scene protocol can be part of a large scene e.g. knowledge sharing between more than two agents and different information shared. The MAP protocol defines the communications between two agents namely the

```
knowledge sharing scene [{%employer,%teamleader}, {!teamleader1, !employer1},

agent(!employee1, %employee) =
request (meeting) => agent (_, %teamleader) then
waitfor
(accept(meeting, $meeting) <= agent ($teamleader, %teamleader) then
($knowledge = getknowledge() then
inform (knowledge,$knowledge) =>agent ($teamleader, %teamleader) then
waitfor
(inform(refer)<= agent ($teamleader, %teamleader) or
inform(norefer) <= agent ($teamleader, %teamleader))
timeout (e)
reject (meeting) <= ($teamleader, %teamleader))
timeout (e)

agent (!teamleader1, %teamleader) =
waitfor (request (meeting) <= agent ($employee, %employee)) timeout (e) then
($meeting = makeMeeting($employee) then
accept  (meeting, $meeting) => agent ($employee, %employee) then
waitfor
(inform(knowledge,$knowledge) <= agent (employee, %employee) then
($ref= do Referral ($employee, $knowledge) then
 inform (refer) =>agent ($employee, %employee)) or
inform (norefer) =>agent ($employee, %employee))
timeout (e)) or
reject (meeting) => agent (employee, %employee)]
```

Figure 7.2: Knowledge-sharing protocol in MAP

teamleader and employee. The aim of the of the scene is for the team leader and employee to exchange information from each other this can be in the form of either exchange of date or information. We start of by stating two different types of terms by prefixing variables names with $ role names with %. We demonstrate two agents which are team leader and employee which have roles %teamleader and % employee. The name of the agent will be bound to the variable $employee. Line 4 which states that any request for an meeting for the protocol will match any agent whose role is a %teamleader, the similar case in line 17 of the protocol will match any agent whose role is the %teamleader which will be bound to the variable $teamleader. The communication in the protocol is non blocking, the send and receive actions will not delay the agent this is why we place the wait for loops to avoid any race conditions. In line 17 the agent will loop until a message is received. If we were to take this loop out the agent will fail to get a meeting request with the team leader and the protocol will terminate prematurely.
One of the advantages of non blocking communication is that we can check for different messages this can be demonstrated from line 9 through to 12 in the protocol which which waits for a refer or a non refer decision.

The semantics of passing messages correspond to reliable buffered non-blocking communication. Sending a message or sharing a message will succeed immediately if an agent matches the definition, and the message (share) will be stored in a buffer at the recipient. Receiving a message requires an additional unification step. The message supplied in the definition is treated as a template to be matched against any message in the buffer. For example, in line 12 of the protocol, a message must be matched and be accepted. The team leader is sharing knowledge, so the variable %`team leader` will be bound to the content of the message, if the match is accepted by the receiver and is successful. The message will fail if no message matches the message template.

When exchanging messages through send and receive actions, a unification of terms in the agent (ϕ^1, ϕ^2) is performed, where ϕ^1 is matched against the agent name and ϕ^2 against the agent role. In line 5 of the protocol, the employee receives an offer from the team leader, and the terms will match any agent or employee whose role is an %`employee`, and this will hold the name of the employee.

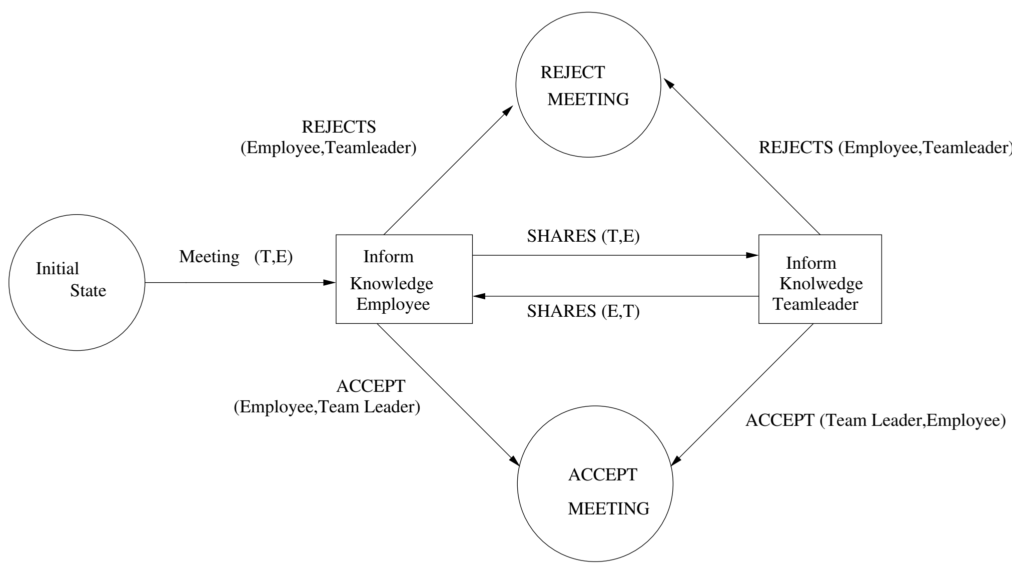


Figure 7.3: Knowledge-sharing diagram

Figure 7.3 gives a visual representation of the process and represents the knowledge-sharing between the two agents, which then will be transformed to code.

Knowledge sharing is the process of knowledge exchange. We model this exchange using two agents i and j. Initially, the sending agent i knows a proposition α and intends that the receiving j agent also comes to know that the proposition α.

In the next section, MAP is converted to PROMELA by simplifying the code. The conversion involves flattening the execution tree through the translation.

7.1.13 Step 4 – MAP to PROMELA

Step 4 of the process consists of MAP encoding to PROMELA, to make it possible for the verification process and checking of properties. The PROMELA coding, for the model-checking process where SPIN checks for successful termination, safety and fairness, is explained and shown in Figure 7.4.

In the figure, `msg0, msg1, ack0, ack1` are symbolic names, `msg0` and `msg1` represent messages. The message sent by the employee to the team leader is `msg0`. The acknowledgement from the team leader is `ack0`, and is confirmed by sending message, `msg1`. The employee then acknowledges confirmation, `ack1`.

Line 1 of the process declares the channel `to_sndr` (team leader agent, i) and line 2 declares the channel `to_rcvr` (employee agent, j). In line 3, a process called `Employee` is created. In line 5, declares a label named `again`.

```
        chan to_sndr = [2] of {mtype};
        chan to_rcvr = [2] of {mtype};
        active proctype Employee()
{
again:
        to_rcvr!msg1;
        to_sndr?ack1;
        to_rcvr!msg0;
        to_sndr?ack0;
       goto again
}
       active proctype Team leader()
       creating a process called team leader
{
   again:
        to_rcvr!msg1;
        to_sndr?ack1;
        to_rcvr!msg0;
        to_sndr?ack0;
        goto again
}
```

Figure 7.4: Knowledge-sharing process in PROMELA

Lines 6 to 9 declare variables that represent messages. In lines 11 and 12, a process called `Team leader` is created. In lines 13 and 14, there is an opening brace followed by the `again` statement. Lines 15 to 18 are the messages that are sent and received between the two processes. The ! symbol after `to_rcvr` in line 15 indicates acknowledgement of a message from the `employee` process. The symbol ? means handshake or confirmation of a message by the `Team Leader` process. The `goto again` statement indicates that the code between the opening and closing braces will be repeated until the last line of code is executed, when the processes end.

The sender, who is the team leader, transmits a message of type `msg` to the receiver, and then waits for an acknowledgement of type `ack` with a matching sequence. If an acknowledgement with the wrong sequence number comes back, the sender will retransmit the message. It is possible for the receiver to time out while waiting for a new message to arrive, in which case it will then retransmit its last acknowledgement.

A timeout will only happen if there are no executable statements at all in any of the currently running processes. The purpose of a timeout is to allow modelling of the recovery actions from potential deadlocks.

The diagram depicted in Figure 7.5 shows a process of knowledge-sharing generated in XSPIN (model-checker tool), with four states, each represented by a rectangle. Each state is labelled with a number, which shows the order in which the processes send and receive messages.

The direction of the arrows between states shows the flow of information, e.g. a message (a piece of data) from sender (`to_sndr`) to receiver (`to_recv`).

The symbol ! indicates that the message is being sent. The symbol ? means that the message is being received. The symbol ? indicates the sender and ! indicates the receiver. The red rectangle indicates the initial stage of the process.

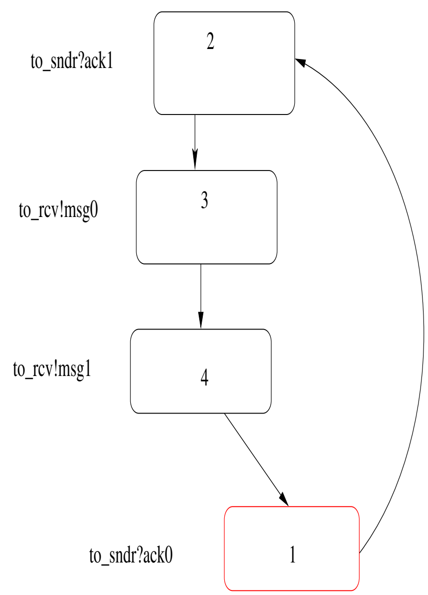


Figure 7.5: Knowledge-sharing process

The movement of knowledge has been successfully analysed through formalisation and verification, with the conclusion that the processes involved terminate, with no deadlocks.

7.2 Background for Knowledge Gap Case Study

This section provides a brief background to the knowledge gap case study Appelbaum et al [74], which focuses on problems occurring in the Data Networking group at Transport Trails Incorporated (TT Inc.). The case study covers the following areas: (1) definition of the problem, (2) an analysis of the problem, (3) conclusions that propose and discuss potential solutions to the problem.

The main issue is the lack of or no training given to employeesAppelbaum et al [74].

The results from this case study Appelbaum et al [74] showed that focusing on perceived control, employee loyalty and employee involvement, employees appeared to be satisfied with their jobs. Of those surveyed, 76% felt that they had a lot of control over their jobs, 76.5% felt that they were valued by the organisation and 72% felt that they had a voice with respect to job involvement. The majority of those surveyed felt that they were given the opportunity to influence decisions, systems and procedures, and had the authority to correct problems when they occur without being reprimanded for making mistakes.

Employee involvement encompasses such popular ideas as employee participation or participative management, workplace democracy, empowerment and employee ownership Appelbaum et al [74]. It can be defined as a participative process that uses the entire capacity of employees and is designed to encourage increased commitment to the organisation's success. The underlying logic is that by involving workers in those decisions that affect them and by increasing their autonomy and control over their working lives, employees will become more motivated, committed, productive and more satisfied with their employee involvement, employee loyalty, all seem to correlate positively with respect to productivity and job satisfaction Cacioppe [16].

The survey conducted in the knowledge gap case study in the IT department Appelbaum et al [74] found that 70.5% of the employees felt that they were not adequately trained in dealing with the wide range of technical problems that they are likely to encounter. From the open-ended questions received, this variable appears to be one of the biggest obstacles hindering job satisfaction and productivity. Among the comments received were: No time for training although it has been budgeted. Not enough training time to understand new technology. Building up the team, delegating work, therefore time to train is a limited resource.

Essentially, employees feel that there is not enough training and that management needs to evaluate the training requirements of the IT department and ensure that employees acquire the requisite technical skills to perform their duties effectively. What is even more disturbing is the fact that there is no time for training even though it is budgeted for.

Each employee in the IT department is allocated a fixed amount for training and it is left at his/her discretion to ascertain which course(s) he/she requires to improve his/her technical skills Robbins [77].

Management needs to map out clearly the training needs for these employees and see to it that their skills are upgraded. Moreover, if time is allocated for training, this may help employees feel more valued. Productivity most probably would increase as well, given that employees will now possess better internal communication skills Appelbaum et al [74].

7.2.1 Discussion

Transport Trails Incorporated (TT Inc.) has various issues in its internal communications within its IT engineering department, resulting in IT engineers leaving the company due to low moral and esteem, and overall dissatisfaction with the company. Most of the employees who left, created a major knowledge gap within the company. An external consultancy agency was brought in to identify and rectify the company's problems and to suggest a strategy to rectify the issues. In the case study Appelbaum et al [74], a list of alternatives and recommendations to meet the objectives was proposed by the consultancy firm.

7.2.2 Definition of the Problem

In 2001, one of the two network architects in the Data Networking group decided to leave TT Inc. for another company. Within a month, the remaining network architect also left. Since these individuals had specialised knowledge and skills that could not be replaced internally, their departures created a major critical knowledge gap. The remaining team members in the Data Networking group also shared their dissatisfaction.

Management was faced not only with the task of filling the open positions and closing the knowledge gap, but also addressing the downward-spiralling effects of the situation impacting on the whole information technology department, due to the staff shortage. The workload for the remaining team members increased as TT Inc. attempted to overcompensate for the loss; but at a certain point, the bubble burst. All ongoing IT projects of the Data Networks group ground to a halt. At this point, team members admitted they were overworked, underpaid, unappreciated and that management was not listening. Also contributing to the situation was the news that two key individuals from the closely aligned Telephony Networking group suffered from stress related issues and were taking extended sick leave.

Productivity and job satisfaction at TT Inc. have declined due to the following: excessive workload coupled with unrealistic deadlines, too much bureaucracy, and a lack of management commitment. The purpose of the survey was to identify the factors having an impact with respect to the organisational problems at TT Inc. The sample consisted of one manager, five team leaders and 11 employees from the Data Networking group. The average number of years of professional experience for the entire sample was 13.5. More importantly, the average number of years worked at TT Inc. for the sample as a whole was 8.5, with a sizeable range of 28.5 years stemming from a maximum of 29 years at TT Inc. to a minimum 0.5 years. The next section will discuss the stepwise modelling for the knowledge gap case study.

7.2.3 Stepwise Modelling for Knowledge Gap

In the proposed framework for knowledge management, knowledge exchange is expressed in epistemic logic, and multi-agent dialogues are translated into a protocol language, which is verifiable by model-checking in a similar way as in the knowledge-sharing case study. The knowledge gap within the agent's knowledge is simulated and the process checks for inconsistencies, termination and fairness.

7.2.4 Step 1 – Selection of Streams

Step one is where the company selects instruments from the questionnaire, allowing determination of which streams need to be formalised for the internal activities. In this case study, the instruments are already known: brainstorming, developing scenarios, discussion with customers/clients and knowing current market fact sheets, these all fall under the category of knowledge gap stream shown in Figure 6.3.

7.2.5 Step 2 – Formalisation Process

Once the company has selected the instruments and the stream has been identified, the next step is to formalise the knowledge gap stream. This is known as the formalisation stage. For information on the language used for formalisation, refer to Section 5.1.

The knowledge gap stream will now be formalised by using the language of epistemic logic. The first section describes how many agents will be involved in the process and what facts are already known or are available:

- Agent i is the manager
- Agent j is the employee
- α = Fact Current knowledge training plan

- β = Fact (New knowledge training plan)

Formalisation of Knowledge Gap

The formalisation starts with the facts the agents know, that is, their initial states, then go through the formalisation process. This will result in one of the agents knowing what they did not know before, receiving the knowledge from the other agent.

Initial state

- $K_i\ \alpha$ – Agent i knows fact α.
- $K_j\ \beta$ – Agent j knows fact β.

Process

- $K_i\ \alpha \rightarrow K_i\ K_i\ \alpha$ – instance of (K4). Agent i knows α, which implies he knows that he knows α.
- $K_j\ \beta \rightarrow K_j\ K_j\ \beta$ – instance of (K4). Agent j knows β, which implies he knows that he knows β.
- $\neg\ K_i\ \beta \rightarrow K_i\ \neg\ \beta$ – instance of (K3). It is not the case agent i knows β, which implies agent i knows not β.
- $\neg\ K_j\ \alpha \rightarrow K_j\ \neg\ \alpha$ – instance of (K3). It is not the case agent j knows α, which implies agent i knows not α.

- $K_i \neg K_j \alpha \rightarrow K_i K_i \neg K_j \alpha$ – instance of (K9). Agent i does not know agent j knows α, which implies agent i knows that he knows agent j does not know α.

End state

- $K_i K_j \alpha \rightarrow K_j \alpha$ – instance of (K10). Agent i knows that agent j knows α, which implies agent j knows α.

7.2.6 Step 3 – Conversion to MAP Knowledge Gap

The MAP encoding is shown in Figures 7.6 and 7.7, which give a graphical representation of the process. After the formalisation of the knowledge process of knowledge gap this is then converted to MAP encoding then to PROMELA for model checking. The protocol in Figure 7.6 shows a knowledge gap protocol description between two agents, the manager and the employee, showing the gap being fulfilled.

The knowledge gap protocol shown in Figure 7.6 effectively captures the knowledge movement through the sequence of interactions between the manager and employee. The variable names of the role names are prefixed by %. There are two roles: the %`manager` who will fill the gap with relevant knowledge and the %`employee` who will be the receiver of the knowledge from the manager. We will now explain how the protocol works. The knowledge gap scene protocol can be part of a large scene e.g. knowledge gap between more than two agents. The MAP protocol defines the communications between two agents namely the manager and employee. The aim of

```
1.  knowledge Gap [
2. % employee
3. method() =
4. wait for
5. (offer(training) < = agent ($manager %manager) then
6. call (deliberate, $training, %manager))
7. timeout(e)
8.
9. method (wait, training)=
10. wait for
11.           accept(training) < = agent(employee, %employee)
12.        or reject(training) < = agent(employee, %employee)
13.
```

Figure 7.6: Knowledge gap protocol in MAP

the of the scene is for the manager and employee to fill the gap, this can be in the form of either information or knowledge. We start of by stating two different types of terms by prefixing variables names with $ role names with %. We demonstrate two agents which are manager and employee which have roles %manager and %employee. The name of the agent will be bound to the variable $employee. Line 4 which states that any request for an meeting for the protocol will match any agent whose role is a %manager, the similar case in line 17 of the protocol will match any agent whose role is the %employee which will be bound to the variable $employee. The communication in the protocol is non blocking, the send and receive actions will not delay the agent this is why we place the wait for loops to avoid any race conditions. In line 17 the agent will loop until a message is received. If we were to take this loop out the agent will fail to get a meeting request with the team leader and the protocol will terminate prematurely. One of the advantages of non blocking communication is that we can check for different messages this can be demonstrated from line 9 through to 12 in the protocol which which waits for a refer or a non refer decision.

The semantics of passing messages correspond to reliable buffered non-blocking communication. Sending a message or sharing a message will succeed immediately if an agent matches the definition, and the message (share) will be stored in a buffer at the recipient. Receiving a message requires an additional unification step. The message supplied in the definition is treated as a template to be matched against any message in the buffer. For example, in line 12 of the protocol, a message must be matched and be accepted. The team leader is sharing knowledge, so the variable %`team leader` will be bound to the content of the message, if the match is accepted by the receiver and is successful. The message will fail if no message matches the message template.

When exchanging messages through send and receive actions, a unification of terms in the agent (ϕ^1, ϕ^2) is performed, where ϕ^1 is matched against the agent name and ϕ^2 against the agent role. In line 5 of the protocol, the employee receives an offer from the manager, and the terms will match any agent or employee whose role is an %`employee`, and this will hold the name of the employee.

The knowledge gap protocol is defined using MAP syntax, as shown in Figure 7.6. There are two roles: the %`manager` and the %`employee`. The employee (agent) has the option to accept the training or to reject it. Each of the roles has associated methods, which define the protocol states for the roles. Figure 7.7 is a representation of the MAP language for the knowledge gap process between the two agents. The knowledge gap begins with an offer from the manager to the employee, which is denoted with the message `offer` (manager, employee). Upon receipt of the initial offer the employee enters a state in which a decision is required, the offer can be accepted or rejected, in which case the protocol terminates. The knowledge gap is effectively captured by a sequence of proposals between the manager and employee.

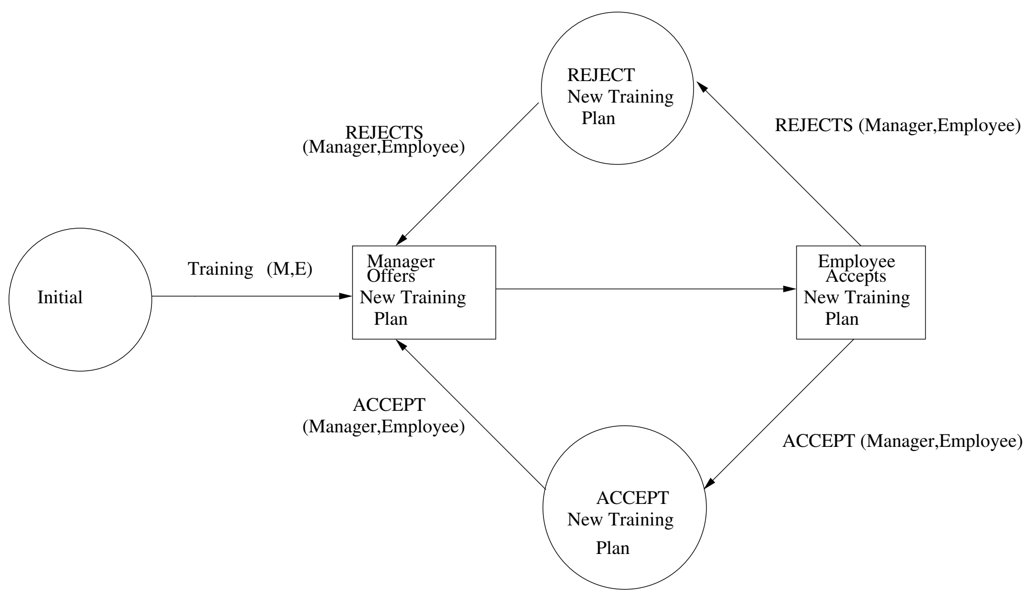


Figure 7.7: Knowledge gap diagram

In the next section explains the deadlock process and compares this against the case studies. The purpose of the illustration of the deadlock process to show how the process can loop if no action is taken.

7.3 Deadlock Process Example

A deadlock happens when two processes are waiting for the same resource and neither process can advance because the other process is preventing it from getting the resource. A deadlock can also occur when two or more competing actions are waiting for others to finish, such as a circular chain, and none of them ever does.

Deadlocks are common in multi-processing where many processes share a specific type of mutually exclusive resource. This situation can be likened to the knowledge gap process where two agents want to fill a gap, with only one piece of information. If receipt of the information is not acknowledged, the sender will deadlock.

PROMELA code with a deadlock is illustrated for a knowledge gap, as shown in Figure 7.8. This example has two agents, "A" and "B", working in an IT support department for a large telecommunications company. Agent "B" fails to respond to an important message sent by agent "A", via a computer software system that logs and alerts agents of communications.

In line 1, there are three symbolic names: `NONCRITICAL` (NC), `TRYING` (T) and `CRITICAL` (C). Line 2 declares and instantiates a global variable called `state`, which is an array. The term `[2]` in the `state` declaration indicates that two messages can be passed through the `mtype` variables declared in line 1. In line 3, a process of type `proctype` is created, which accepts a value of type integer. Line 4 shows the beginning of a process in the non-critical state and line 5 shows it is non-critical. Line 6 shows that the value

```
1.  mtype = { NONCRITICAL, TRYING, CRITICAL};
2.  mtype state[2];
3.  proctype process(int id) {
4.  beginning:
5.  noncritical:
6.  state[id] = NONCRITICAL;
7.  if
8.  :: goto noncritical;
9.  :: true;
10. fi;
11. trying:
12. state[id] = TRYING;
13. if
14. :: goto trying;
15. :: true;
16. fi;
17. critical:
18. state[id] = CRITICAL;
19. if
20. :: goto critical;
21. :: true;
22. fi;
23. .goto beginning;}
```

Figure 7.8: Deadlock Process

of `NONCRITICAL` is assigned to variable `state` and is then followed by an `if` statement.

In line 8 a technical support agent logs a defect for a customer on his incident support software system and sends it to agent “B”, asking for the issue to be resolved within 30 minutes. At this stage the message is non-critical. Due to a major backlog on agent “B”’s computer system, the message is missed. After 45 minutes, the software displays a message on the computer screen in attempt to get the agent's attention, line 12. After two hours, the system changes from state `TRYING` to state `CRITICAL`, until the message has been acknowledged by agent "B". Once the message has been received the system enters an NC state and the process restarts again. When an agent in a process is waiting for information that it needs from another agent, it will enter a critical process state where it will loop over and over again, hence forming a deadlock.

If the guard conditions in the loop construct between 7 and 10 evaluate to false then the system will go to step 12 where the value in the variable state `TRYING` is then evaluated, lines 13 to 16. This step is again repeated between lines 18 and 23. After line 23 is executed the code loops back to the `NONCRITICAL` stage and repeats the lines of code from 1 to 23, therefore creating a deadlock.

Figure 7.9 shows the deadlock as a diagram. The deadlock occurs because the manager process does not have a matching receive statement in the employee process, and the defined channel `glob` in the channel declaration has been set with a zero capacity, so that no messages can be stored. Therefore on executing the code, a deadlock will occur.

In both case studies, successful termination of the processes with agents, who have delivered and received messages, was achieved. An example of a deadlock showed what can happen if the process is not successful and how it would behave.

The next section discusses step 4, the PROMELA language used for model-checking in SPIN, and compares the knowledge gap process with a

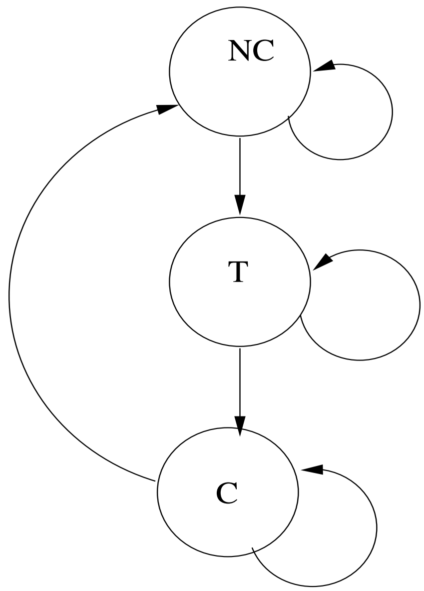


Figure 7.9: Deadlock Representation

deadlock process.

7.3.1 Step 4 – MAP to PROMELA

An explanation of the PROMELA coding has been given, matched against the line number of the code, which is the model-checking process where SPIN checks for successful termination, safety and fairness.

Firstly, the code in Figure 7.10 is translated. The process shows one-way communication between two processes, the `manager` and the `employee`. The `manager` process sends the value 2 in its local channel variable to the `employee` channel via the global channel, and makes it available to that process. The `employee` process transmits a message of the proper type via a rendezvous handshake on that channel and both processes can be terminated.

```
1.  mtype = { msgtype }
2.  chan glob = [2] of { chan };
3.  active proctype manager()
4.  {chan loc = [1] of { mtype, byte };
5.  glob!loc;
6.  loc?msgtype(121)
    }
7.  active proctype employee()
8.  { chan who;
9.  glob?who;
10. who!msgtype(121)
11. }
```

Figure 7.10: Knowledge gap process in promela

When the `employee` process dies, channel `loc` is destroyed and any further attempts to use it will cause an error.

Line 1 of Figure 7.10 declares a symbolic name, `msgtype` of `mtype`. Line 2 declares a channel called `glob` which is global to any process and can store one message. In line 3 a process is created. The prefix `active` means that the process is active. In line 4, a local variable is declared and initialised to 0. Line 5 sends it to the other channel, that is the local channel of line 6, which receives the message. In line 7 a second process is created. The prefix `active` indicates that a process of type `employee` is instantiated. Line 8 declares channel `who`. Line 9 retrieves a message from channel `who`. Line 10 receives a message value type.

A graphical representation of the knowledge gap process is depicted in Figure 7.11, shows a process of knowledge-gap generated in XSPIN (model-checker tool), with 3 states, each represented by a rectangle. The direction of the arrows between states shows the flow of information between the Manager and Employee. The red rectangle indicates the initial stage of the process. In state one, the manager sends a message to the employee, indicated by (`glob!loc`). The symbol ! indicates that the message is being sent. The second state shows that the employee is receiving the message, indicated by (`loc?msgtype`) . The symbol ? means that the message is being received. The final state is 0, which means that the message has been successfully received and the process has terminated.

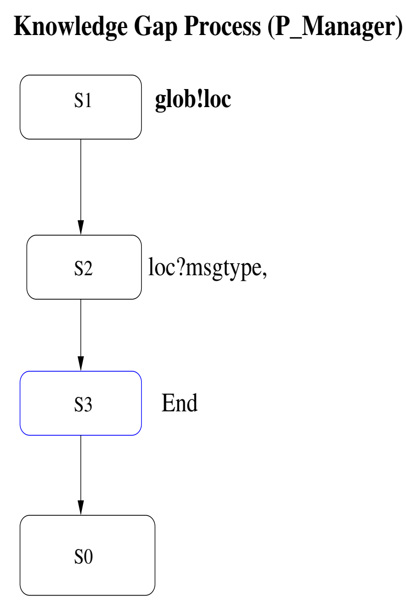


Figure 7.11: Knowledge gap process

It is concluded that the framework allows for modelling multi-agents in a knowledge management environment, allowing knowledge exchange. The correctness of properties, behavioural aspects and the change of information used in the specification in both of the real-life case studies for knowledge-sharing and knowledge gap have been verified. The processes have been checked for consistency, termination and fairness. All processes involved, such as multi-agents in a given environment, have been successfully verified using the SPIN model checker. The framework can be applied to a wide range of organisations, either with knowledge management initiatives or without. It can identify problem areas and further verify the processes involved and investigate any issues in the organisation by applying the same method as for the real-life case studies. If the framework were to be expanded, it would need more than two agents involved in the framework as there would be multiple agents involved and deal with groups of knowledge opposed to what a single agent knows. The KM framework developed is very diversified and can be applied to SMEs and large organisations in all industry sectors.

In both case studies, successful termination of the processes with agents, who have delivered and received messages, was achieved.

Chapter 8

Evaluation

8.1 Introduction

Five companies were approached and had agreed to take part in the study by completing a questionnaire see appendix back of thesis. It was intended to compare the results obtained from the from all of the companies to assess and evaluate the understanding of knowledge management in their organisations and for them to assess our knowledge management framework if it will of beneficial for the organisations to use. Two of the companies were large organisations and three were in the SME category. The reasons for the selection of the companies were chosen to compare with the literature review conducted in the thesis and how this compares to the theoretical aspect of the research. The following companies were selected: Bank of Scotland, Abbey Tours, Innes Johnston Estate Agents and Solicitors. JM Breckenridge and Lochaber Game Services. These companies were specifically selected as they meet the criteria of our study e.g. companies selected comprised of larger organisations and small enterprises this allows our research to compare the practical aspect of the data collected against the theoretical aspect discussed in the literature view.

We now give a brief description and background of the companies selected for our study.

Bank of Scotland

The Bank of Scotland PLC is a commercial and clearing bank based in Edinburgh, Scotland. With a history dating to the 17th century, it is the second oldest surviving bank (the Bank of England having been established one year before) in what is now the United Kingdom, and is the only commercial institution created by the Parliament of Scotland to remain in existence. It was also the first bank in Europe to print its own banknotes; it continues to print its own sterling banknotes under legal arrangements which allow some UK banks to issue currency. On 17 September 2007, The Governor and Company of the Bank of Scotland became Bank of Scotland PLC, as part of the HBOS Group Reorganisation Act 2006. Since 19 January 2009, the Bank of Scotland has formed a key part of the Lloyds Banking Group, following the acquisition of HBOS by Lloyds TSB Group.

Abbey Tours

Abbey Tours is a Destination Management Company, with offices in Edinburgh and Dublin. Abbey Tours work exclusively with the Travel Trade and provide the full range of services in Scotland for Groups, On-line Individual Travel and Corporate Travel. Abbey Tours specialise in the business of

Group Travel. hey offer a wide selection of itineraries, incorporating both the popular classic programmes, as well as some new and original offerings. Their group department can assist in creating programmes which best match the needs of clients. They also provide with different price options, designed to meet the budget the clients have in mind.

Their philosophy is a simple one, they wish to make it as easy as possible for their Trade Partners to sell Scotland in their marketplace. They do this by offering an efficient and reliable service, together with the flexibility that is necessary to make business run smoothly. Their objective is to design programmes which meet the different needs of their clients, and match clients pricing requirements.

Innes Johnstons Estate Agents and Solicitors

Innes Johnston is a firm of Scottish solicitors and estate agents based in Fife with offices in Kirkcaldy, Glenrothes and Leven. The estate agency department is based in Glenrothes and covers all our offices from there. Innes Johnstons take pride in providing a professional and personal service. With very approachable partners and around 25 support staff, they have wide experience in most of the aspects of law that private clients and small to medium sized businesses and organisations are likely to require. They are always happy to speak to you whether your enquiry is large or small and are committed to providing you with an efficient service in a friendly and approachable way.

JM Breckenridge

The company is a family run business founded by James Breckenridge in 1973 and has been run by the McDonald family for the past 20 years. As a result this has allowed Breckenridge to become one of the most established and successful suppliers of fresh produce in Scotland. JM Breckenridge being is a family run business who like to stress that they have a genuine care for customers and aim to deliver an excellent level of service to satisfy their customers. JM Breckenridge understand to ensure high standards are maintained they ensure that every member of the team at Breckenridge works incredibly hard from the boss to the store worker. JM Breckenridge operate out of two fully refrigerated depots. Their head office is located in Oban and other depot is located in Fort William. Their main customers are hoteliers, restaurants and retailers. At Breckenridge they aim to cater to the customer no matter how big or small the order may be! All their goods are class 1 and are delivered in fully refrigerated vehicles to maintain excellent standards even on the rare hot sunny days they experience in Scotland! Their products range from:Fresh fruit,Vegetables, Herbs, Exotics Dairy produce. JM Breckenridge receive a delivery of goods from their suppliers daily which ensures that they can provide their customers with the highest possible level of quality combined with value for money. These goods are then delivered to the customer as soon as possible to ensure maximum quality. Our objective is to achieve a stock turnover period of 24 hours which is vital to deliver the high standard of service we aim for at Breckenridge.

Lochaber Game Services

Lochaber Game Services is a family run quality butchers established in 1994. The current partner had taken over the business from her father back in 2008 and when her husband then joined as a partner. We have since gone from strength to strength and now employ: full time butcher, who have been in the butcher's trade for many years and is a highly skilled and valued employee.

They also have a delivery driver and also a qualified butcher who carries out deliveries to Inverness,Perth and Glencoe.

They have a member of staff who deal with accounts and takes orders from customers. The company prides itself in high quality, fresh local produce which is then expertly prepared by our butchers to our customers individual needs.

All the companies agreed to complete a preliminary questionnaire which were provided to senior management or owners of organisations. The questionnaires was developed to gather data on knowledge management this includes awareness, implementation and general questions relating to knowledge management. The questionnaire comprised of specific instruments relating to our KM framework in regards to how useful it was for the companies and weather or not they thought it would be beneficial for them.

This chapter of the thesis provides an analysis of how companies perceives knowledge management in their organisations and the tools they use. The questionnaires used in the methodology section will will also give an evaluation of our KM framework as there are questions which relate to the use of our framework. The survey was conducted within Scotland area where businesses were given the questionnaire to fill out. They survey was conducted by preparing questionnaires for the businesses to fill out.

8.1.1 Research Approach and Design Methods used

To adequately evaluate knowledge management in organisations a design was required to facilitate the measurement of KM in organisations and a evaluation of the proposed KM framework. The questions were designed so the results would give multiple data points for the research. One advantage of the design is that it is possible to observe the trends on the dependant variable.

8.1.2 Approach to research

In order to have successfully completed this chapter it was crucial to prepare questionnaires for the businesses. Sampling was carried out by analysing each section of the questionnaire, before the questionnaire were prepared it was necessary to structure the questionnaires in a particular way to achieve maximum results. The next stage was to arrange for letters or e-mails being sent to the businesses that were going to be involved in the survey. We had successfully arranged the companies to take part in the survey and were delighted to fill in the questionnaires.

8.1.3 Research Setting

The study was conducted with five businesses located in various parts of Scotland. All of the clients were owners or managers of the business.

8.1.4 The study population and sample

According to [15] a population is defined as all elements including individuals, objects and events that meet the sample criteria for inclusion in the study. The study population consisted of two large organisations and three smaller companies who are suppliers in the Highland area. Two of which are larger organisations, Bank of Scotland and Abbey Tours Tour operators. A convenient sample of five companies were selected who were all operational and trading, [64] defines a sample as elements selected with the intention of finding out something about the sample size from which they are taken. A convenient sample consists of subjects included in the study because they happen to be in the right place and the right time. [70]. Available subjects were entered into the study until a sample size was reached.

The sample size of five companies were the total of subjects who were willing to participate in the research and who meet the sampling criteria during period of data collection.

8.1.5 The Sampling Criteria

Subjects included in the sample were selected to meet specific criteria. The businesses had to meet the following criteria to be included in the sample. These were: the business had to be in operation, willing to participate in the survey, have employees working in the organisation, have to be in a manager or supervisor position who makes business decisions or owners.

8.1.6 The Study Population and Sample

The participants involved in the sample were managers and owners of the five companies selected for the questionnaires. The participants (businesses) who had taken part in the study were based in North of Scotland and Central Scotland.

8.1.7 Data Collection instruments

A questionnaire was chosen as data collection. A questionnaire is a printed self -report form designed to elicit information that can be obtained through the written response of the subjects. It is stated by [15] that information obtained through a questionnaire is similar to that obtained by an interview but the questions tend to have less depth.

The Data was collected with the aid of questionnaires to firstly evaluate our framework and receive information on what the companies perception was on knowledge management and compare this to the literature review which was conducted.

The questionnaires were decided upon because of they ensured a high response rate as the questionnaires were distributed to respondents to complete and were collected personally by the researcher,They require less time and energy to administer,there was less opportunity for bias as they were presented in a consistent manner, most of the items in the questionnaire were closed ended, which made it easier to compare the responses to each item

Apart from the advantages listed above questionnaires have their weaknesses: e.g. there is the question of validity and accuracy [15] the subjects might not reflect their true opinions but might answer what they think will please the researcher and valuable information may be lost as answers are usually brief.

One questionnaire was used to collect the data to get information on how organisations use knowledge management and if they have even heard of the terms. The second section is used to collect data on how useful our knowledge management framework would be to the organisations. The questionnaire consisted of mostly of closed ended questions and few open ended questions as these provide more diverse detail. In the open ended questions the subjects were required to respond in writing whereas closed ended questions had options which were determined by the researcher [15] open ended questions were included because they allow subjects to respond to questions in their own words and provide more detail. Closed ended questions were included because they are easier to administer and to analyse. They are also more efficient in the sense that a respondent is able to complete more closed ended items than open ended items in a given period of time [70].

The questions were in English and was not required to translate in any other language. The questionnaire consisted of various sections which was aimed at gaining information on the designation of the respondent, as this information could assist the researcher when interpreting the results e.g. whether the respondent understood the questions asked regarding the KM framework and knowledge management and if they had such systems to facilitate them with knowledge management.

8.1.8 Data collection procedure

Questionnaires were e-mailed and personally distributed by the researcher to businesses to complete. The researcher did not have to complete any questionnaires for the businesses as they were quite capable of completing it nor did they require any assistance as the questionnaire had explicit instructions on how to complete it.

8.1.9 Reliability and Validity

It is stated by [70] that reliability as the degree of consistency with which an instrument measures the attribute it is designed to measure. The questionnaire which was completed by the businesses revealed consistency in the responses. Reliability can also be ensured by minimising sources of measurement error like data collector bias. Data collector bias was minimised by the researcher's being the only one to administer the questionnaires and standardising conditions such as exhibiting similar personal attributes to all respondents e.g. friendliness and support.

8.1.10 Validity

The validity of an instrument is the degree to which an instrument measures what it is intended to measure [70]. Content validity refers to the extent to which an instrument represents the factors under study. To achieve content validity, questionnaires included a variety of questions on the knowledge management to businesses and questions on the way they utilise knowledge along with questions asked in relation to our proposed framework on KM.

Questions were based on information gathered during the literature review to ensure that they were representative of what businesses should know about knowledge management. Content validity was further ensured by consistency in administering the questionnaires. All questionnaires were distributed to subjects by the researcher by e mail or personally. The questions were formulated in a simple language for clarity and ease of understanding. Clear instructions were given to the subjects.

three of the subjects completed the questionnaires when they were sent or handed in to the respondents. Although there was no presence when the questionnaires were filled out by them but there was a degree of confidentiality as the questionnaires were sent directly to respondents. Seeking subjects who are willing to participate in a study can be difficult particularly if the study requires a lot of time to complete if the number of the businesses approached to participate in a study declines, generalising the findings to all members of a population is not easy to justify.

8.1.11 Pretesting the Questionnaire

A pretest refers to a trial administration of an instrument to identify flaws. When a questionnaire is used as a data gathering instrument, it is necessary to determine whether questions and directions are clear to subjects and weather they understand what is required from them. This is referred to as the pretesting of a questionnaire [70].

The researcher pretested the questionnaire on five respondents meeting the set criteria on various businesses three businesses which were smaller organisations and two large organisations. All of them answered the questions and no single question was changed following the pretest.

8.1.12 Ethical Considerations

The conducting of research requires not only expertise and diligence, but also honesty and integrity. This is done to recognise and protect the rights of human subjects. To render the study ethical, the rights to self determination, anonymity,confidentiality and informed consent were observed.

Verbal permission to conduct the research study was obtained from from each individual businesses who participated in the study. Subjects consent was obtained before they completed the questionnaire. [15] define informed consent as the prospective subject's agreement to participate voluntarily in the study, which is reached after assimilation of essential information about the study. The subjects were informed of their rights to voluntarily consent or decline to participate and to withdraw participation any time.

The subjects were informed about the purpose of the study, the procedures that would be used to collect the data, and assured that there were no potential risks or costs involved.

Anonymity and confidentiality were maintained throughout the study. [15] define anonymity as when subjects cannot be linked, even by the researcher, with his or her individual responses. In this study anonymity was ensured by not discussing the businesses involved to anyone else and other information regarding the confidentiality information which was not included.

When the subjects are promised confidentiality it means that the information they provide will not be publicly reported in a way which identifies them [70]. In this study, confidentiality was maintained by keeping the collected data confidential and not revealing the subjects identities when reporting or publishing the study [15].

The ethical principal of self determination was also maintained. Subjects were treated as autonomous agents by informing them about the study and allowing them to voluntarily choose to participate or not. Also information was provided about the researcher in the event of further questions or complaints.

8.1.13 Data Analysis

After the data was collected it was organised and analysed. For analysis of closed ended questions data was analysed by content analysis by the researcher by comparing the results of open ended questions and closed ended questions. For each item listed in the questionnaire.

Data Analysis:

In this section we compare the results from the data gathering from the three out of five businesses who participated in the study. These results are gathered from the questionnaires which were completed in February 2013 the companies background is listed at the beginning of this chapter. The aim of the data analysis is to

We will now discuss the feed back back from each instrument listed on the questionnaire.

We will compare the results of the following companies: Innes Johnstons and Bank of Scotland Innes Johnstons and JM Breckenridge. two of which are smaller organisations and one is a multinational corporation. All of the companies have been operating for more than 10 years. Innes Johnstons has less than 50 employees working on the organisation and the Bank of Scotland employees over 250 employees and JM Breckenridge who have fewer than 50 employees.

Instrument 4 refers to the type of business model the organisation has, 3 of the companies have Business to Consumer model providing products and services to their customers. Question number five addresses what the company thinks of knowledge management? Both of the companies answered "e" and . which refers to something that can be beneficial to the organisation which basically means both of the companies weather a large organisation or smaller enterprise consider KM as being an important element in their organisation. one stated that it was just an management fad. Question no six refers to what the organisations think of knowledge management? all of the companies answered 2 which is a "business focused approach" which is the collection of processes that govern the creation dissemination and utilisation of knowledge to fulfil organisational objectives. Question no 7 states whether the companies recognise knowledge as a part of their asset base? 2 of the companies have indicated yes which states that they are aware of KM being a important element of their company strategy and one was not sure and answered "can't say".

Question 8: All of the companies indicate they have values system or culture intended to promote knowledge sharing but do not have written KM policies.

Question 9: addresses the attitude of senior management with respect to KM in their organisation. Bank of Scotland selected (a) which sees it as a very important and provides full support. Innes Johnston and JM Breckenridge sees it as very important but hardly supports it.

Question 10: Refers to which sources triggered your organisation to put into effect the knowledge management practices that they currently use, Innes Johnstons and JM Breckenridge had selected internal management and triggered to out in KM practices. The Bank of Scotland had selected External sources which had triggered the organisation to put the KM practices in place e.g. Universities, technical colleges public labs or business school and professional trade or industrial associations or federations.

Question 12 relates to which technologies have the organisations implemented in their organisation for knowledge sharing, knowledge acquisition and knowledge capture. The most common technologies selected by the companies were: Internet, Intranet, E-commerce, data warehousing decision support systems and data management systems.

Question 14 addresses which knowledge management methodologies are used in the organisation, Bank of Scotland had selected all from the list provided apart from (h) and (I) see appendix as where Innes Johnston had selected two from the list which was mentor and coaching. JM Breckenridge had selected mentor, coaching and rotational assignments, it was surprising to note that the training option was not selected as this one of the most important in respect to filling the knowledge gap.

Question 15, relates to how the organisations captures knowledge, Innes Johnston have selected knowledge from industry sources such as industrial associations, competitors, clients and suppliers and the Bank of Scotland have selected all the items apart from item (4) JM Breckenridge have selected item 3 which relates to dedicating external resources for communicating.

Question 16 relates to training and mentoring in the organisation, Innes Johnston selected option (b) from the list which is informal training relating to knowledge management and Bank of Scotland have selected all options apart from "a" and "c". JM Breckenridge selected options "b" "d" which relates providing informal training and encourage experienced workers to transfer their knowledge to new or less experienced employees.

Question 17 relates to how the workers communicate, how the employees share knowledge and information. The Bank of Scotland have selected option "a" and "b" from the three options and Innes Johnstons and JM Breckenridge have selected option "b" out of the 3 options.

Question 18. This question is related to what extent the knowledge is shared within the organisation and how easily it is accessed. According to Bank of Scotland most of the options selected were in the category of to a great extent and to some extent as this is dependant on the information shared and what security restrictions have been applied to gain access at different levels. Innes Johnstons have selected all options as to some extent and one under not shared which was the information on future plans. JM Breckenridge selected from to some extent to don't. In relation to other comments on this question the company had selected mostly don't know this could be due to the lack of understanding of the knowledge management in their company.

Question 19. This question was aimed to find out how long it takes for organisations to retrieve information both of the companies had selected option (b) few hours as where JM Breckenridge selected "week or more "this suggest perhaps the information is not properly organised or not available.

Question 20. This question is relating to the reasons knowledge management is used in the organisation, Bank of Scotland have found most of the points to be important and critically important. Innes Johnstons have have also found these points to be important and some what important and JM Breckenridge had found these points to be important to some what important.

Question 22, This question address the benefits of using KM practices in organisations e.g. effectiveness of results of using KM. 2 of the companies had selected most of the items to be from neutral to very effective and JM Breckenridge had mostly selected Neutral and less of the effective and very effective items.

Question 23, addresses how much the company spends on KM practices, all of the companies selected less than 5

Question 24, address the knowledge retention in organisations. Bank of Scotland will be affected by knowledge retention largely by relocation and down sizing and external factors. Innes Johnston is affected by knowledge retention largely by retirement and employees leaving to get a better job. JM Breckenridge are affected to employees who have been offered a promotion in affect lose the knowledge from those employees.

Question 25, problems faced by the organisation using IT for knowledge Management, Bank of Scotland had given a high score on unsuccessful due to technical problems with the It system. Innes Johnston and JM Breckenridge had similar issues in regards to having technical problems with the IT system in regards to lack of training and system too complicated.

Question 26, challenges in implementing KM practices, The major factor which was facing the Bank of Scotland was that everyday use did not integrate into normal working practice. Innes Johnston JM Breckenridge responded that the problems they had faced was technical problems when implementing KM practices and lack of identifying the proper IT tool for JM Breckenridge.

Question 27, The biggest hurdle implementing KM in the organisation for all the companies was facing the biggest challenge of attracting and retaining talented people.

Question 28, Perception on the respondents view on how satisfied they were on the KM strategy they were using. Bank of Scotland had stated that item "c" was very important as this relates to customer focused knowledge comparing to others and Innes Johnston had stated almost all items were very important in relation to their satisfied with their KM strategy and JM Breckenridge had also had similar responses being satisfactory to medium less than other companies who participated.

Question 32,Responsibility for knowledge management practices, Bank of Scotland stated that HR and IT along with Executive management were responsible for KM in their organisation. Innes Johnston had only selected Executive management team as they are have a smaller hierarchy and less structural. JM Breckenridge had states HR and Executive level were responsible for knowledge management practices.

Question 33, relates to if there were any other KM practise the organisations had used other than the ones listed on the questionnaire. All that had participated mentioned no.

All of the companies Innes Johnston, Bank of Scotland and JM Breckenridge were asked to evaluate our framework of knowledge management questions were asked to give feedback in relation to our KM framework.

We will now evaluate the usefulness of the framework by analysing the responses from the companies in regards to our KM framework:

Bank of Scotland

The questions stated in the questionnaire gave the opportunity to the company to evaluate our KM framework the following responses were recorded. Bank of Scotland understands the proposed framework for knowledge management and states that it would be very useful for organisations to analyse the flow of knowledge in the organisations as our frame comprises of the underlying processes of knowledge management and this generic framework which is applicable to all organisations will benefit from such framework. Bank of Scotland also stated the framework would be very useful to model the flow of knowledge as in many cases it gets unnoticed. Currently the Bank of Scotland does not have a framework in place to support its knowledge management practices apart from a KM databases which they use to retrieve information. The Bank of Scotland fully supports our framework of knowledge management. Innes Johnston also found the proposed KM framework to be very useful for their company in terms of knowing what knowledge flows in their organisation and get a better understanding of what knowledge is required and what they have available. Although they have stated that they currently adopt a informal framework meaning they have a structure in place e.g. share knowledge through informal sources e.g. discussions meetings and share information through databases which comprise of information. Innes Johnston fully supports our KM framework and states that it would support the organisations of realising the potential knowledge a company may have. In regards to JM Breckenridge they have have given a different view on our framework, we asked the question if they had understood the KM framework? they had stated that ”Yes they do understand the framework but thinks it can lack actual benefits” From their prospectus they struggle to see results on sales to transfer from KM work meaning how can the framework increase sales, we perhaps think they have not understood the framework, although they had stated in the questionnaire, question 5 they have stated that KM is just a management fad and was did not really think much of it, it is important to realise that it is through the KM framework they can not only increase their sales by knowing what knowledge they have on their customers but also realising the potential knowledge they might lack of. With this framework they can analyse the knowledge that exists in their company and verify certain properties of knowledge. JM Breckenridge were doubtful that the KM framework would help them in any way. They do not currently use any framework for knowledge management in their company as they stated they use ”transfer of knowledge from older employees to young and pass on in built promises” from this statement we can see there is an informal system in place to transfer knowledge it would be interesting to know what knowledge is being transferred to younger employees and if they document this explicitly. JM Breckenridge would like to see how this framework can increase the sales revenue as mentioned earlier. Although the company does deal with knowledge and finds important but does not support it, this can be due to a number of reasons e.g. do not have the financial capacity to implement expensive systems and the complexity of such systems.

Question 2 stated if the companies would benefit from such a framework? Both companies answered yes.

Question 3 were also asked if they companies used a existing framework in which they could compare, unfortunately they did not have any existing framework in place.

Finally they were asked if they had any comments regarding the KM framework, no comments were given as all was answered in the questionnaire.

8.2 Conclusion

The researcher used qualitative survey design. The questionnaires were administered by the researcher to collect the data from a sample of five businesses. The questionnaire had both closed and open ended questions. The sample characteristics included businesses who were willing to participate in the study.

Permission was obtained from the businesses. Consent was obtained by the subjects themselves. Anonymity, self determination and confidentiality were ensured during administration of the questionnaires. Questionnaires were e mailed and handed personally to subjects or owners of businesses to ensure validity. Reliability and validity were by pretesting the questionnaire.

This chapter described the research methodology, including the data collection instruments as well as strategies used to ensure the ethical standards, reliability and validity of the study. It also compares the data received from respondents by analysing each instrument against each other.

8.3 Further Scope

Comparing various KM models to the one we proposed, it allowed further analysis and verification of the KM processes in the call centre, as demonstrated in the knowledge-sharing scenario. Other issues in the case study were also identified Appelbaum et al [88], by filling out different instruments that relate to the other communication issues and identifying the stream that must be formalised for each particular issue. There is further scope of modelling groups of agents on a larger scale using multi-agents.

Single-agent systems may be extensive to groups or multi-agent systems. Following the standard provided by Moses and Vardi [40] we can syntactically expand the language of propositional logic with n knowledge operators, one for each agent involved in the group of agents under consideration. The main difference between the semantics given for a single-agent and a multi-agent semantics is roughly that n accessibility relations are introduced. A modal system for n agents is obtained by joining together n modal logics where for simplicity it may be assumed that the agents are consistent in the sense that they may all be described by the same logical system. An epistemic logic for n agents consists of n copies of a certain modal logic. In an extended epistemic logic it is possible to express that some agent in the group knows a certain fact, that an agent knows that another agent knows a fact etc. It is possible to develop the logic even further: Not only may an agent know that another agent knows a fact, but they may all know this fact simultaneously. From here it is possible to express that everyone knows that everyone knows that everyone knows, that. That it is common knowledge.

A group has distributed knowledge of a fact φ if the knowledge of φ is distributed among members, so that by pooling their knowledge together the members of the group can deduce φ, even though it may be the case that no member of the group individually knows φ. Lets say if we where to take an e.g. from knowledge sharing case study if agent Alice knows that bob should share knowledge with either carol and Susan and charlie knows that bob should not share the knowledge with carol, then together Alice and charlie have distributed knowledge of the fact that whether bob needs to share knowledge with susan, although neither alice nor charlie individually has this knowledge. While common knowledge can be viewed as what " any one " knows, distributed knowledge can be viewed as what a "wise man" one who has completed knolwedge of what each member of the group knows wouldk now. This common knowledge and distributed knowledge are very useful in helping understand and anatlyse complicated situations involving groups of agents within any organisation.

The basic modal operator of epistemic logic, usually written "K", can be read as "it is known that," "it is epistemically necessary that," or "it is inconsistent with what is known that not." If there is more than one agent whose knowledge is to be represented, subscripts can be attached to the operator K_1, K_2, etc.) to indicate which agent one is talking about. So $K_a\varphi$ can be read as "Agent a knows that φ." Thus, epistemic logic can be an example of multimodal logic applied for knowledge representation. The dual of "K", which would be in the same relationship to "K" as $\Diamond$ is to Box, has no specific symbol, but can be represented by $\neg K_a \neg \varphi$, which can be read as "a does not know that not φ" or "It is consistent with a knowledge that φ is possible". The statement "a does not know whether or not φ" can be expressed as $\neg K_a \varphi \wedge \neg K_a \neg \varphi$. In order to accommodate notions of Common knowledge logic common knowledge and distributed knowledge, three other modal operators can be added to the language. These are $E_{\mathcal{G}}$, which reads "every agent in group G knows;" $\mathcal{C}_{\mathcal{G}}$, which reads "it is common knowledge to every agent in G;" and $D_{\mathcal{G}}$, which reads "it is distributed knowledge to every agent in G." If φ is a formula of our language, then so are $E_G \varphi$, $\mathcal{C}_G \varphi$, and $\mathcal{D}_G \varphi$. Just as the subscript after K can be omitted when there is only one agent, the subscript after the modal operators E, C, and D can be omitted when the group is the set of all agents.

Chapter 9

Conclusion

This thesis has covered the importance of KM and the KM models presented in the literature and how these models differentiate from the proposed model. The proposed model uses formalisation using epistemic logic to show the movement of knowledge in SMEs and large organisations, by modelling of multi-agent communication carried out in the context of case studies relating to problem-solving and reasoning. It was shown that knowledge-sharing and knowledge gap can be modelled as a multi-agent protocol and translated into MAP, and then to PROMELA, and model-checked using SPIN. A verifiable knowledge exchange between individuals modelled as multi-agents was presented. This model-checking approach allows the detection of internal enterprise knowledge exchange that conflict with each other, e.g. by allowing unauthorised agents to access propriety knowledge. Any inconsistencies in the process itself can cause non-termination.

This research can benefit all organisations as it is imperative that knowledge is properly disseminated, e.g. by managing knowledge in order to meet existing needs, and to identify and exploit existing and acquired knowledge assets. Our framework supports KM as it identifies the relevant streams that are crucial for business.

Further research is required in the KM field to understand the multi-agents involved in different scenarios, such as groups of agents. Common knowledge can be added to groups of agents to analyse the flow of information in groups.

Organisations increasingly realising the importance of knowledge management, but the future of knowledge management must be more than just realising its importance; the main problem addressed by Toumi [90] is the evolution of knowledge management. Larger organisations realise the potential of KM but SMEs are still in a position where they need to be more aware of KM. Organisations need to use KM tools more effectively to get a competitive edge in the market. It is stated by Wiig [95] that "Enterprises have turned to explicit and systematic knowledge management (KM) to develop the intellectual capital needed to succeed".

Organisations do realise the importance of KM and are willing to pay a high and continuing price for an emphasis on short-term improvements, but it should be realised that this is not a short-term issue, it should be focused on the long-term use of knowledge management tools for efficient and effective use of KM, according to the research literature on KM in organisations. The early emphasis was on information system and organisational development and shifted to intellectual capital management and competence management towards the end of the 1990s. Next, social learning, organisation sense-making, disseminate successful innovation and change management became prominent themes in knowledge management. However, organisations now need to look into the future on how revolutions can be managed "if knowledge is power where are the limits of organisation knowledge creations" Toumi [90]. It should also be noted that attitudes must change in order for KM to become an enjoyable aspect of work, see Wiig [95], who states that: "As people begin to expand their understanding of knowledge as an essential asset, they are realising that in many ways the future is limited only by imagination and the ability to leverage the human mind."

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