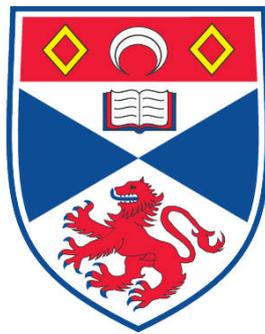


**WORKAROUND AS A CRAFT SKILL  
OF THE COMPUTERISED PAPER PRODUCTION PROCESS**

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WORKAROUND AS A CRAFT SKILL  
OF THE COMPUTERISED PAPER PRODUCTION PROCESS

Annop Supachayanont

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## Table of Contents

Abstract	iii
Chapter 1: Introduction	1
Thesis Outline	1
Chapter 2: Michael Polanyi's Philosophy of Tacit Knowledge	8
Introduction	8
1 – The logic of tacit integration	11
Accumulation of experience	19
Hammering nails	21
Sense-giving & sense-reading	22
Induction and classification in skills with logical/intellectual expression	24
Problem-solving as a heuristic act	27
Polanyi with Merleau-Ponty, Dilthey and Rothschild	30
2 – Critical Assessment of Michael Polanyi's Epistemology	36
Tacit knowledge is subjective	37
Different kinds of tacit knowledge	42
Purposes and conception of skills	46
Scientific objective knowledge	48
Conclusion	51
Chapter 3: Methodology	56
Introduction	56
1 – Interpretive research and tacit knowledge	57
The hermeneutic process of studying meaning	59
2 – Thick description	64
Secondary research	68
Focus on narratives	68
The critical incident technique	72
In-depth techniques	75
Qualitative interviews	75
Observation	78

Analysing	80
Reliability & validity	83
Research Site	84
Conclusion	87
Chapter 4: Impact of computer technology in paper production process	88
Introduction	88
1 – Work in the paper production process	89
2 – Impact of computer as an automation technology on work and skills	93
3 – Development of Computerisation in paper production	99
Decision-support features of the modern computerised systems	98
4 – Operators’ skills a in contemporary papermaking work environment	105
Conclusion	116
Chapter 5: Mobilising Tacit Knowledge	119
Introduction	119
1 – Papermaking, technology and tacit knowledge	119
2 – Grade change process	130
Conclusion	156
Chapter 6: Conclusion	158
Appendix 1: Pictures of the Control Room	165
Appendix 2: Screenshots of the Control Systems	167
Bibliography	170

## **Abstract**

Tacit knowledge and craft skills are widely discussed in management research and practice. Impacts of computer technology on knowledge and skills attract great interests in the field of organisation research. Research in the paper-making and other continuous process manufacturing reveals that the computer leads to skills to cope with abstraction of work. However, none of the key work explicitly addressed the issue of the tacit knowledge and skills.

This research draws on the philosophy of tacit knowledge of Michael Polanyi to explain an exercise of tacit knowledge and skills in critical problem-solving. The interpretive research uses a critical incident technique and a thickly descriptive method to study the production workers' exercise of their unique problem-solving capability at the disruptive events to the routine activity.

The finding shows that a workaround to overcome limitation of the control system are key to successful problem-solving at a computer interface. In contrary to a number of studies that placed an exclusive focus on an ability to perform abstract reasoning, the successful workaround presupposes the workers' traditional physical and sensory-based exposure to the work process.

## **Chapter 1: Introduction**

### **Thesis Outline**

Tacit knowledge is a widely debated subject in management research. Michael Polanyi is widely known for his notion of the tacit knowledge and a distinction between tacit and explicit knowledge.<sup>1</sup> His emphasis on the tacit knowledge covers all exercises of knowledge and skills, both explicit and tacit, rooted in our personal tacit dimension (Polanyi M., 1967b: 4). This opposes the view that the articulate and the inarticulate knowledge are two mutually exclusive entities (Cook S. D. C. and Brown J. S., 1999; Musgrave A. E., 1974). There has been considerable attention on division of the knowledge into articulate and inarticulate forms. Gilbert Ryle, for example, makes a distinction between the knowing-how and knowing-that (Ryle G. 1946). Indeed, one of Polanyi's key contributions is the interplay between the articulate and the inarticulate knowledge as we deliver skilful or intellectual performance as in solving a problem. Experience allows us to cope with novel situations with heightened subtlety as we learn to become more adaptive and to less follow a strict logical pattern. It is positively related to an ability to improvise – i.e., to make a quick and reliable decision without prior stipulation (Weick K. E., 1998). It will also be shown that the same tacit faculty allows us to effectively overcome the problem inherent in a computing system's limitation as an act of workaround.

An impact of a computer technology on a work process has become a subject of interests since its debut in manufacturing since early 1960s.<sup>2</sup> This dated back to the skill debates on the consequence of the computerisation, as an automation technology, in the workplace. The debate originated from the work of

Braverman's (1974) *Labor and Monopoly Capital*. The scientific management method, or Taylorism, seeks to deliver maximum economy in factory production by imposing capitalist control over labour process. Management should monopolise knowledge over how production process should be organised (Blackburn P. *et al.*, 1985: 43). To obtain the lowest cost of labour necessitates the deskilling thesis: "substituting simple for complex labour" by dissolving "esoteric skills" into simple and discrete steps (Wood S., 1982: 26; Braverman, 1974: 100; Elger T., 1982: 26). Taylorism is concerned with the control of labour at any given level of technology (Braverman H., 1974: 110). Automation technologies from mechanisation to computerisation are tools to impose increasing level of control. The result is "a replacement of skilled workers by machines or machine operatives ... with any *remaining* skill allocated to a few specialised workers" (Thompson P., 1989: 91). Technological progress leads to a steady degradation of work: a divorce of conception from execution restricts workers to simple manual operations. "[K]nowledge, responsibility and judgement are taken from the workers" (Wood S., 1982: 13-4). Microprocessor places a strong tendency for removing discretion from the workers, thanks to its ability in mimicking intelligent human responses (Thompson P., 1989: 109).

The deskilling thesis attracts a wide range of debates. In essence, it is often criticised for an uncritical adoption of the scientific management ideology, a uniform transition to the subordination of labour that does not consider an uneven pattern of rationalisation and mechanisation (Wood S., 1989: 15; Elger T., 1982: 28; Littler C., 1982: 122). Other management methods in addition to the scientific management are not considered (Manwaring T. and Wood S., 1985: 174). Several factors limit managerial imperatives for control, and there exist

unique circumstances facing firms and workforce specific to firm, locality and industry (Manwaring T. and Wood S., 1985: 189-90). The automation technology has the potential to sacrifice the traditional know-how in favour of the theoretical and scientific knowledge in various industrial settings, with an exception to the craft industries (See Nichols and Beynon, 1977; Blauner, 1968). Relative strength of workers' collective control of the strategically most important task prior to an introduction of the new technology or production technique determines an effectiveness of an exercise of labour power and political struggles in the workplace. Social organisation of skill, through bargaining, partially determines what skills are recognised. Evidence has shown not only slower real-world change in skill than what one might expect from Braverman's analysis, but also only a partial shift to the new technology in many factories (Lee D., 1982: 154, 160; Attewell P., 1992: 65; Manwaring T. And Wood S., 1985: 184).<sup>1</sup> Positive and social definition of skill is hard to find, making it unclear what changes in skill are being measured against (Thompson P., 1989: 92). Workers' fate also varies in accordance with external economic condition and availability of employment (Lee D., 1982: 147, 9; Manwaring T. and Wood S., 1985: 191).

New technology creates opportunities for new skills, and leveraging the utility of the traditional ones. For the former, an automation substitutes for tasks that are relatively simple allows workers to concentrate on more challenging and complex aspects of the job (Adler P., 1992; Giuliano V., 1982; Hirschhorn L., 1984). When the workers in automated plants give up manual operation and

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<sup>1</sup> See for further details.

become monitors and troubleshooters of the process, it reveals that an emerging type of skill increases cognitive demand and complexity, focusing on diagnostic skills and an ability to cope with uncertainty and mutual interdependence (Adler P., 1992; Blauner R., 1964; Faunce W., 1965). The pre-computer automation result in a net upgrading of skill levels among the blue-collar workers, whilst the computerisation increases workers' responsibility and skill in a wide range of manufacturing during the 1970s and 1990s.<sup>2</sup> Blauner R. (1964), and Nichols T. and Beynon H. (1977) found *reskilling* evidence in chemical, textile and printing industries; that is, the debased craft skills with emergence of the new tacit skills, both conceptual and physical. The extent to which manual dexterity is built into machines depends on standardisation of the production process (Blauner R., 1964: 35-6). And the greater the level of mechanisation, the greater the repairs, maintenance and control over the production process are deferred to specialist roles, as is evident on auto assembly lines where major operations consist only of basic manual work performed by semi-skilled workers (Blauner R., 1964: 36, 95-6).

For the latter, the technology produces a symbiosis between the formal, intellectual aspect of a job and the informal skills (Cavestro W., 1989: 234). New tactile element of the automated production become central to an effective operator, as when the machine tool operators develop “the ability to discern, within a noisy environment, muffled sounds that indicated something was about to go wrong” (Attewell P., 1992: 49). “Material and symbolic work cannot be completely segregated” – the workers concomitantly work in the material world

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<sup>2</sup> See Attewell P. (1992: 55, 83)

and the world of representations. (Barley S., 1996: 417, 418). Working with the computerised automation presupposes theoretical knowledge through formal training and the empirical knowledge through day-to-day contact with the production process. Anticipating and resolving problems are characterised by “*ad hoc* measures,” “improvisation” and “experimental behaviour” at unexpected irregularities such as breakdowns (Adler P, 1992: 135; Cavestro W., 1989: 219-34).

In short, the above has led to the conclusion that the computer, as an automating technology, poses a *deskilling* tendency towards work practice: the workers experience a loss of salience of their traditional skills in the computer-mediated work environment. However, real-world practice reveals an imperfection to this rationale. In the craft industry with a non-standardised production process still demands the esoteric skills of the journeymen workers that cannot be completely taken over by the technology (Blauner R., 1964: 35-6).

The paper-making is one of the manufacturing that relies on multi-crafted employees (Smith M. R., 1999: 695; Holmes J., 1997: 21). The absence of complete explication of the production process, thanks to unmeasurable parameters, operation unknowns and variability of raw materials, makes it impossible for a complete automatic process control (Zuboff S., 1988: 305-6). Yet, evidence of the impact of the computerisation on the paper-making skills has been mixed. Reliance on sophisticated instruments that bypass workers’ senses takes away the centrality of their traditional skills (Barley S. R., 1996). According to Zuboff (1988), the computer capabilities to automate and informate have led to more abstract work, programmable intelligence and visible organisational memory (Zuboff S., 1988: 390). The *intellective skills* that emerge

mark a shift from sense-making activities based on physical cues, toward explicitly constructing meaning from “abstract cues,” “explicit inferential reasoning,” and “procedural thinking” (Zuboff S., 1988: 95-6). “Mastery in the symbolic medium” is founded upon combined exercises of memory and imagination. The ability to create abstract mental images as accurate referents to a physical world is the key to accomplish work (Zuboff S., 1988: 87). However, Vallas S. P. (2001), Penn R. and Scattergood H. (1985), and Huys *et al.* (1999) concluded that computerisation in the papermaking practice still presupposed traditional knowledge and experience of paper manufacturing based on intuition and learnt experience.

Study of literatures revealed that the recent computer systems assisted the production workers by 1) automating control and monitoring functions, and 2) by aiding their problem-solving by the combined ability for experiential learning, adaptive problem-solving, and simultaneously taking into calculation several process parameters, their interactions and dynamics .

This research is interested in the exercise of unique skills in the computer-mediated paper-making environment. We looked at the workers’ problem-solving at a critical work phase, by employing an interpretive research methodology. Changing of a production grade interrupted an on-going activity that causes the subjects to articulate what has been previously taken for granted. Research methodology appropriate to Polanyi’s framework applies critical incident interviews, an in-depth interviews and an observation technique to produce a thick description of the subject’s lived experience, based on narratives (Tsoukas H., 2005; Patriotta G., 2004). The subjects articulate what has previously been taken for granted at an interruption of the automated process.

Focusing on the critical non-routine work phase allows the researcher to study the tacit knowledge as their background knowledge appears in the foreground (Patriotta G., 2004: 68). The finding revealed the workers' workaround was unique to the modern papermaking process: they workaround the system's limitation to overcome process disturbances and the automatic control to improve overall process efficiency. The workaround tends to be temporary: a fix that consists of initiating change in one area to affect – or offset – others, whilst tolerating certain parametric deviation. The ability to workaround depends upon both accumulated experience working with computer-generated symbols and traditional physical-sensory cues.

## Chapter 2: Michael Polanyi's Philosophy of Tacit Knowledge

### Introduction

The chapter introduces Michael Polanyi's philosophy of tacit knowledge. This is important for two reasons. First, Polanyi has emerged as a key thinker in contemporary debates about work, particularly knowledge work. It is hard to find literature in the field without reference to a term tacit knowledge (Tsoukas M., 2005: 142). Second, Polanyi understands tacit knowledge as a necessary and vital element of all skill. He requires us to think of skill in a holistic way: individual and collective; physical and intellectual; and all dimensions that are necessarily part of all work.

Several key literatures in organisation studies define the tacit knowledge as practice-based. For example, Tsoukas H. (2005: 119-23, 128), Cook S. D. C. and Brown J. S. (1999: 381-400) define the term as the capability to draw distinctions based on an appreciation of context or theory, whilst according to Nonaka I. *et al.* (2002: 42) the tacit knowledge is a context-specific "justified true belief" created in "social interactions among individuals and organisations."

One of the well-known references to Polanyi is his distinction between the tacit and explicit knowledge. Collins H. (1993) and Blackler F. (1995) classify knowledge into the embrained, embodied, encultured, embedded and encoded. Spender J-C. (2007, 2008) makes a typification of knowledge-as-data, knowledge-as-meaning and knowledge-as-practice. Collins H. (1993) and Collins H. *et al.* (1997) defines "behaviour-specific actions" that encompass the coordination of apparently uncorrelated behaviours into concerted acts. The fact that we live as part of a society presupposes socialisation that underpins tacit

knowledge or apprenticeship (Collins H. 1993; Collins H. *et al.*, 1997). Johannessen K. S. (1988) stipulates that explicit rules only exist as a link in social life. Examples, experience and judgement can only be partially articulated: it is only through examples and familiarity of experience that we learn to deal with, describe, interpret and learn from new situations (Johannessen K. S., 1988: 287, 296).

However, the over reliance on tacit-explicit distinction with little attention on process of knowing and organising causes potential separation of theory from practice (Patriotta G., 2003: 350). “Organisational knowledge is always the outcome of interactive and controversial social process” (Patriotta G., 2001: 944). Cook S. D. C. and Brown J. S. (1999), Lam A. (2000), Nonaka I. (1994), Nonaka I. and Takeuchi H. (1995), Spender J.-C. (1993, 1996) and Tsoukas H. (2005) analyses interactions between individual and collective forms of the tacit knowledge that guide problem-solving activities and patterns of interactions among organisation members. Interactions among individuals and their environment allow them to address novel problem situation (Nonaka I. and Takeuchi H., 2002: 43).<sup>3</sup> We solve problem by engaging in a productive inquiry involving interplay among the explicit and tacit knowledge possessed by individuals and groups (Cook S. D. C. and Brown J. S., 2002: 89). Indeed, Orr J. (1990), Brown J. S. and Duguid P. (1991), Patriotta G. (2004) and Tsoukas H. (2005) focus on narratives as carriers of the tacit aspect of knowledge based on Polanyi’s framework. The narrative is a form of sensemaking: ways of talking about organisations that reflect shared perception (Weick K. E., 1995). To engage in the collective is to engage in a discursive practice, sharing narratives of the practitioners (Tsoukas M., 2005: 123). Disruptions to routine activities

provide an occasion for articulating an ongoing flow of action and sense-making as narratives, moves and decisions (Patriorra G., 204: 68).

Well-known terms in management literature which typify the exercise of tacit knowledge include, but are not limited to, “communities of practice” (Wenger E., 1997; Brown J. S. and Duguid P., 1991), “core competencies” (Hamel G. and Prahalad C. K., 1994), “situated cognition”, “legitimate peripheral participation” (Lave J. and Wenger E., 1991), “organisational epistemology” (Krogh G. and Roos J., 1995), “bridging epistemologies” (Cook S. D. C. and Brown J. S., 1999) and “knowledge as practice” (Spender J-C., 2008).

This chapter has two sections. The first explains the core idea of Polanyi’s philosophy of knowledge. Although he uses many conceptions to refer to the general notion of tacit knowledge, each with slight changes of emphasis over time, this does not reflect confusion on Polanyi’s part. For example, his notion of motor skill in bicycle riding depicts the exercise of skill that is made explicit through physical content. For interpretation, his conceptions of signs and symbols, and sense-giving and sense-reading refer to skill working with linguistic content. For scientists, his notion of classification and induction addresses skill working with intellectual content. In any case, his philosophy of TK is important because its holistic nature views all exercises of skill as rooted in tacit knowledge sharing similar structural form. This structural form is what Polanyi calls the “logical structure of tacit integration.” An exercise of skill results from the integration of its parts. Further, such process can be achieved only tacitly, and not all the parts are specifiable.

The section also locates Polanyi's philosophy in the context of wider philosophical debate. We examine Merleau-Ponty, Dilthey, and Rothschild, all of those who influenced Polanyi. Merleau-Ponty's phenomenology underlies Polanyi's notion of tacit integration; we use our body as an instrument to interpret environmental cues. Equally, Dilthey's idea of "lived experience" influenced Polanyi's existential notion of 'indwelling' in exercising tacit knowledge. Rothschild's thinking provides Polanyi with his notion of language and communication, as the basis for embodied meaning-making. The objective of this section is to consider the relationship and the uniqueness of Polanyi's philosophy of tacit knowledge.

The second section reviews Polanyi's critics, and his defence. Critics such as Musgrave, Popper, Harré and Jelfs insist on the objective and explicit nature of knowledge, and question the validity of the intangibility of tacit knowledge. This section aims to question the justification of his thought in context of philosophical debates.

### **1 – The logic of tacit integration**

This section explains Polanyi's key idea: "we know more than we can tell"(Polanyi M., 1967b: 4). All knowledge and skills are rooted in a tacit dimension. The features and process of tacit knowledge that cannot be made wholly explicit in which its applicability is in the physical exercise of skills in using a tool and embracing an intellectual framework. The comparability between accumulation of the tacit knowledge and experience provides the potentiality for adaptive learning and flexible problem-solving. The section also describes Polanyi's different emphasis on the tacit knowledge according to what

becomes evident in its expression. This is classified into the physical, semiotic and intellectual theme.

Polanyi sees perception as a paradigm for the logic of tacit integration to explain the process. In perception, the work of tacit knowledge is present as we perform an act of “tacit integration,” a process which we actively make tacit use of clues we are aware only in a subsidiary fashion (Prosch H., 1986: 53-66). In effect, we integrate sensations and feelings into the perceived object that gives meaning to these sensations and feelings, without which they do not possess (Prosch H., 1986: 53). We are making an “intelligent effort” in order to see the objects of which these are the qualities, or else they are merely meaningless fragments of sights (Polanyi M., 1958: 98-9; 1969: 169-70). Moreover, perceiving an object is a skill of meaningful integration of sensory clues through a sustaining conscious effort (Prosch H., 1986: 54).

Polanyi’s notion of tacit knowledge is based on the Gestalt theory that the organised whole is greater than the sum of its parts (Prosch H., 1986: 8, 52-3, 65)

“[O]ur perceptual experiences do not arise because we consciously or unconsciously apply rules or concepts to putatively meaningless collections of data gathered at our sensory receptors. Rather we have been formed by our previous experiences and by our immersion in our present perceptual environment to the extent that the information taken in by our senses is already, in normal circumstances, endowed with meaning”(Smith B., 1988: 2-3).

More specifically, “our sensory contents are a matter of holistic structures, experienced as being tied intrinsically to certain kinds of surrounding conditions and to certain characteristic presuppositions and outcomes” (Smith B., 1988: 2-3). Similar to our actions, they are complex wholes, and not mechanical or passive responses to stimuli of an equal value. They are “wholes whose elements

manifest different degrees of salience. ... Human action is ... a matter of integrated behaviours whose physiological and psychological sides are fused together” (Smith B., 1998: 4-5). Thus, “we have been shaped in certain ways by past experiences—the world in which we act is positively and negatively charged, in different ways, by a pattern of values,” which attract or repel our successive actions. “[C]omplex higher order actions are executed by being broken down into constituent, relative routine tasks, each of which may be performed without thought or conscious reflection” (Smith B., 1998: 3).<sup>4</sup>

For Polanyi, tacit knowing is “the understanding of the comprehensive entity in which the two terms—the proximal and distal—together constitute by relying on our awareness of its particulars for attending to joint meaning” (Polanyi M., 1967b: 13).<sup>5</sup> The tacit integration is an act that relies on our awareness of the first term for actively and intentionally attending to the second term. We are aware of the former only in light of our focus on the latter.

The structure of the tacit integration is composed of two terms. The tacit knowing involves the integration of subsidiary clues. We move from these clues to a focal object. There are two kinds of the subsidiary clues (Polanyi M., 1969: 139-40; Polanyi M., 1958: 55-6, 58). While we cannot directly observe the “subliminal” clues as we do with the “marginal” clues, we do not attend to them directly whilst focally focusing on the object of attention.<sup>6</sup> They are non-focal since our awareness of them is only subsidiary to the focal awareness of the object (Polanyi M., 1958: 56-7). In case of perception, the subliminal clues consist of events in the body we cannot directly observe, whilst the marginal clues are those we could observe directly but do not attend to directly. Subliminal clues enter into the focally perceived objects as other non-subliminal

feelings, even though we cannot make focal perceptions of them as they function in such a way (Prosch H., 1986: 72). We use subliminal particulars subliminally in the personal act of perception—of integration.

Subsidiary and focal clues are functionally related in a non-reciprocal “from-to” fashion. We have the subsidiary awareness of the first term (the proximal term); we know them but are unable to tell thoroughly what they are. The second distal term is what we focus our attention on. We rely on our awareness of the first term for actively and intentionally attending for the second term (Polanyi M., 1966: 9-13, 86; Polanyi M., 1968: 31). In perception, our subsidiary awareness of clues or parts participates in our perception by merging into our focal awareness of the whole. The subsidiary awareness also participates by guiding our action. The deliberateness of our action merges the two kinds of our awareness in the act of knowing. It is the integration that involves our active and intentional action as part of all knowledge (Polanyi M., 1969: 127-9).

We are aware of the first term only *in light of* our focus on the second term. That is, we are only subsidiarily aware of the first term with respect to our focal awareness of the second term. Our “phenomenal” awareness of the subsidiary or proximal terms, when they are subliminal, resides entirely in the appearance of the focal or distal term to which we are attending. We are not aware of the subsidiary clues by themselves. Our awareness of them and their appearance comes from the other thing—the focal term—to which we are attending theory Prosch H. (1986: 68). This is because our awareness of the first term arises in term of the “semantic” or meaning that it enters into the appearance of the second term. The meaning of the first term is grasped or understood and becomes signs of the second term (Polanyi M., 1967: 12). The meaning of the subsidiary

term operates as clues or signs pointing to something else in an act of an intelligent integration (Prosch H., 1986: 68). The meaning is grasped, seen or created by a mind, with the intention of finding or achieving meaning—to achieve a comprehensive and intelligible integration.

The process of “tacit inference” has the pointing quality of meaning where a person A makes the word B (by integrating it), meaning the object C (as B bears on C); i.e., by endowing B with a meaning that points at C. B is, thus the pointer. This is the directive, or vectorial, way of attending to the pointer—our subsidiary awareness of the pointer. A meaningful relation of the subsidiary to the focal is formed by the action of a person who integrates one to the other, and the relation persists as the person keeps up this integration. The recognition of pointing makes up the tacit inference (Polanyi M., 1967a: 301-25).

Central in the process of knowing is the bodily root of knowledge. Our body is the ultimate instruments of all our external knowledge. We use bodies—by our organs, senses and brains—in the act of knowing. Meaning arises either by integrating clues in our own body or by integrating clues outside, and all meaning known outside is due to our subsidiary treatment of external things as we treat our body. This also applies to the construction of such elements as language, theory, and history: they act subsidiarily through which, and by the sole means of which, we come to the focal knowledge of reality by sending out and receiving back signals which to a greater or lesser degree resonate with the reality (Puddefoot J. C., 1993: 32). Since, “[t]he theory of the body ... is already a theory of perception," the embodied mind, the meaning-maker, makes his connection to the world by his intentionality (Jha S. R., 2002).

In effect, we do interiorise these subsidiary clues. To interiorise means to identify ourselves with the objects under questions to make them function as the proximal term. By dwelling in them we make them mean something on which we focus our attention. They are means of making certain things function as the proximal terms in the integration of particulars. By indwelling means we are aware of the subsidiary clues in their “bearing on” the comprehensive entity, which they constitute. In other words, we cannot logically or theoretically deduce externally an actual perception, but we “dwell” in subliminal particulars alongside other non-subliminal clues. The joint meaning of the particulars which an entity is rooted existentially is not perceived by looking at them but by dwelling in them. Thus, we grasp, internalise, and dwell in it. We also interiorise external things including tools, probes or instruments of any kind. We know what we become aware of only through our actual dwelling in its particulars (Prosch H., 1986: 72-3). We internalise tools as we use them, treating them as extension to our body. According to Polanyi,

“Our subsidiary awareness of tools and problems can be regarded now as the act of making them form a part of our own body. We pour ourselves out into them and assimilate them existentially by dwelling in them” (Polanyi M., 1958: 59).

When we make a thing function as the proximal term of tacit knowing, we incorporate it in our body or extend our body to include it, so that we can dwell in it. Clothes, spectacles, probes and tools, for example, when in use, function like our body and resemble our body closely as we rarely know them focally. Indeed, whenever we experience an external object subsidiarily, we feel it in a way similar to that in which we feel our body. Thus, all the subsidiary elements are interior to the body in which we live: i.e., we dwell in all subsidiarily

experienced things. Our body submits to the operations of which the particulars we are virtually unknown. These largely unspecifiable operations cannot be replaced effectively by any focally controlled operations. This example evidences our capacity to integrate and endow with meaning those things of which we possess only a subsidiary awareness.

The same is true in understanding between persons sharing the knowledge of the same comprehensive entity. When one person produces and the other apprehends a skilful performance of the former, the performer co-ordinates his moves by dwelling in them as part of his body, whilst the watcher tries to correlate these moves by seeking to dwell—or interiorise—in them from the outside (Polanyi M., 1961b: 458-70).

The objects experienced in perceptions are salient figures against a less salient ground (Smith B., 1988: 6). They are not separate items independently existing side by side from each other and the subject. The object of experience is locked together within larger networks of interrelations, manifesting interdependence and mutual involvement (Smith B., 1988: 6). Any linguistic sign that represents the object of experience is linked in parallel networks. The signs represent objects not only from their direct empirical association, but they also stand in relation to other signs that track the relations of the objects. For example, children learn meanings of the words not just from the ostensiveness; they can perform cross-checking of contexts (Smith B., 1988: 6).

Seeing an object against its background in the perception is performed by purposive mental act (Jha S. R., 2002: 71-3). When the background functions subsidiarily in terms of the object's appearance, we are aware of them only in

terms of the object's appearance. Both focal awareness and subsidiary awareness that exist functionally is related in a single, purposive act of mental awareness. Perception and knowledge is a result of an intentional and purposeful effort toward an ideal, which we aspire (Prosch H., 1986: 61). However, if the factors in perception below the focal awareness are not factors we are at least subsidiary, or "sublimally," aware, then perception becomes a caused event, not a single, purposive act (Prosch H., 1986: 6).

In integration, we take into account a host of rapidly changing clues, for example, when we perceive moving hands with our eyes. The meaningful, but non-explicit, integration transforms what we perceive into a coherence among the varied and changing clues in the form of single unchanging object; i.e., the hand moving. This can only be achieved by an internal action we are quite incapable of controlling or feeling in itself. It is our craving to find strands of permanence in the tumult of changing appearances that leads to the integration. It is an intention to bring experiences under intellectual control, or an intended intellectual coherence towards the goal of attaining meaning (Polanyi M., 1958: 18, 73, 103-4, 132-3; Polanyi M., 1969: 114; Prosch H., 1986: 60). The logical structure of our awareness is unspecifiable. We do not observe these workings in themselves, the unspecifiability of clues means that there are many features and clues we could not identify: we only understand objects from the particulars from which we attend to it.

We do not need to be aware of all the clues being integrated in the act of "tacit integration," nor are we aware of the process. The process is achieved only tacitly and informally. For example, we know a person's face and can recognise it among thousands. We rely on our awareness of the features of human

physiognomy for attending to the characteristic appearance of a face, yet we are unable to specify all the features (Polanyi M., 1967b: 10). We also recognise the moods of human face, and only are able to tell vaguely by what signs we know. Even the descriptive sciences, which studies physiognomies cannot be fully described in words or pictures (Polanyi M., 1985: 5). We know them tacitly and assume in all other instances of tacit knowing the correspondence between the structure of comprehension and the structure of the comprehensive entity.

### **Accumulation of experience**

Since our past experience is a form of marginal clues, our previous meaningful integration of clues informs what we have become used to seeing in the past (Prosch H., 1986: 57-8). They slip into the backs of our minds and function as part of the subsidiary clues forming the background for a new integration of clues with objects (Polanyi M., 1958: 97). This non-deliberative visual mechanisms are primary determination of our perceptual background (Prosch H., 1986: 59). The past experience, as marginal clues, only works as further specifications of what has already become our perceptual background by the operation of our visual mechanisms. It becomes “partial solutions” or “latent learning,” which are combinations of acts previously learnt. They are manifested in the new problem situation. These prior solutions enable subjects to see problem as a whole (the second term), as they interconnect in this whole by becoming parts of appropriate routes towards reaching a solution. This process is also irreversible. They participate as clues in this new whole, within which is born the act of insight. The act towards completion is directed from the subsidiary clues, both marginal and subliminal, as partial solutions in forms of clues and a hunch.

As we know more (i.e., accumulating more clues), our experience expands.

That is,

"the subject will acquire, in part through repetition, a repertoire of behaviour patterns, a wealth of different portmanteau reactions (walking, running, tripping, sliding, lifting, pushing, speaking, writing), to which he may resort, spontaneously, from occasion to occasion" (Smith B., 1988: 5).

We accumulate a repertoire of behaviour patterns as a wealth of different "portmanteau reactions" combinations that we spontaneously resort, as if they were "written into our muscles" (Smith B. (1988: 5). In other words, our experiences necessarily involves of the gradual building up of aptitudes of general powers of responding to a situation type in ways which bring about a spontaneous but provisional equilibrium of action and cognition (Merleau-Ponty M., 1983: 99, 103, 240). These can be transferred immediately as the situations arise. This is a feature of human learning, which at the same time is adaptive. "Since our bodies have acquired a sophisticated repertoire of portmanteau reactions in relation to the different words of our language and to the different patterns of combination of words, ... this allows us to improvise with language, to enjoy successful linguistic combinations and to detect unsuccessful combinations through the displeasure they may cause" (Smith B., 1988: 5-6).

As the refinement of languages and formalism follows the acquisition of new insights, the crucial element of the level of apprenticeship in learning is to deal with how to use bodies, languages, and theories as we acquire the skills needed to perform the tacit integration (Puddefoot J. C., 1993: 33). We use— dwell in—the constructed language and theories to acquire the understanding of that which is not in this same sense constructed, and to which those constructions

are alien (Puddefoot J. C., 1993: 33). Moreover, the subsidiary knowledge may be brought into focus and formulated as, following Polanyi, maxims, the explicit knowledge. However, such specification cannot be exhaustive (Polanyi M., 1958: 88). The skilful use of clues applies to other learning, by "a joining and mutual adjustment of information from our sense organs about conditions inside and outside our bodies and from our memories" (Jha S. R., 2002: 72).

There are various illustrations of the logic of tacit integration. Polanyi provides many different conceptions of his idea in his several writings. Here we will not explain all but offer some of the different emphases. It is possible to categorise his illustration as skills that are explicit in their physical content (skill in action); semiotic content; and intellectual content.

### **Hammering nails**

Polanyi's explanation of using a hammer to drive a nail provides a fine description of skills explicit in its physical expression. He explains the roles of the proximal and distal terms in tacit integration as we attend to both nail and hammer in a different way. We focus on the object of our attention—wielding the hammer effectively—whilst not relying on the nail, hammer or our palm in themselves but subsidiarily as tools.

“We watch the effect of our strokes on the nail and try to wield the hammer so as to hit the nail most effectively. When we bring down the hammer we do not feel that its handle has struck our palm but that its head has struck the nail. Yet in a sense we are certainly alert to the feelings in our palm and the fingers that hold the hammer” (Polanyi M., 1958: 57).

To illustrate the work of subsidiary term, Polanyi explains that we bring down the hammer, we are alert to the feelings in our palm and the fingers that

hold the hammer.

“They guide us in handling it effectively, and the degree of attention we give to the nail is given to the same extent but in a different way to these feelings. The difference may be stated by saying that the latter are not, like the nail, objects of our attention, but instruments of it. They are not watched in themselves; we watch something else whilst keeping intensely aware of them” (Polanyi M., 1958: 57).

We subsidiarily know the particulars in an instrumental manner but focally ignore them (Polanyi M., 1958: 88). “The subsidiary or instrumental knowledge ... is not known in itself but is known in terms of something focally known ... and to this extent it is unspecifiable” (Polanyi M., 1958: 88). We have a subsidiary awareness of the feeling of the palm of our hand, which is merged into our focal awareness of effectively driving in the nail (Polanyi M., 1969: 145).

### **Sense-giving & sense-reading: the semiotic expression**

Polanyi explains skills working with linguistic content through notions of sense-reading and sense-giving. They are the key conceptualisation of a semiotic property of an articulated language. The articulated language not only refers to the language we use like English, but also to signs and symbols that have meaning bearing on something else (Polanyi M., 1967b: 7). Signs, symbols or words operate in our awareness differently from what they signify. They function as signs of something else; they function subsidiarily as a medium or tool to the knowledge of something else in which there is an interest taken whether that is known as a sign is consciously known or not. They function as clues that are known in a subsidiary way as bearing upon a meaningful integration of themselves. The result of this integration, in turn, forms that which is known in a focal way (Polanyi M., 1967a: 192-3; Polanyi M. and Prosch H., 1975: 69-70). In other words, they are subject to necessary completion or animation through

the personal experience of the subjects (Smith B., 1988: 9). They are transparent; when listening, our primary focus (i.e., the focal awareness) is directed to the objects the words refer to and not on the words themselves (Smith B., 1988: 9).

Also expressed in the language are values as a cultural form of meaning. The values are special expressions of language that play major role in expressing interests, directing thought and guiding action toward the consummation of existential and experiential meaning. In a descriptive sense, their meaning points out features that exist apart from our knowing of them. A statement such as “that garden is beautiful” is experiential, expressing an existential meaning. It is a cultural form of meaning capable of communicating to others, and a designator of a real feature (Gulick W. B., 1999: 30-1). Another cultural form of meaning involves accepting idioms, and conceptual and interpretive framework sustained and embodied in that language. The basic beliefs, or premises, are tacitly observed. They constitute a whole body of acceptances that are logically prior to any particular assertion or piece of knowledge. They cannot be "logically" derived from other beliefs (Sanders A. F., 1988: 191). We understand meaning in the full context of the experience (Jha S. R., 2002: 75).

To understand meaning, we control sequences of integrations that alternate between sense-reading and sense-giving. Communicating via letter is an example of a sequence of three integrations. Polanyi explains that a person composes a letter as he travels in a country never visited before requires 1) an intelligent understanding of sights and events (i.e., sense reading: immediately experiencing the meaning); 2) the composition of verbal account of this experience (i.e., sense-giving: meaning is only present in thought) and; 3) the interpretation of this

verbal account by the reader to reproduce the experience reported (i.e., sense-reading). On the one hand, the writer's sense-giving in the use of universal terms in language is an act of conceptual subsumption. On the other, the reader's sense-reading in the intelligent reading of a description is an act of conceptual exemplification. Communication in writing then involves the process of consecutive integration of the composer, and reintegration of the receiver (Polanyi M., 1967a: 190).

### **Induction and classification in skills with logical/intellectual expression**

Polanyi shows in his writings the notion of science as intellectual activities are coherent with the notion of tacit knowing. In several writings particularly in 1947 *Personal Knowledge* (1958), he rejects the formalisation of scientific knowing. His *Tacit Dimension* (1967) integrates his philosophy of science into a general epistemology that accounts for science as an intelligible extension of the informal logic that structures perception and cognition in general. "Science, argued Polanyi, is "far from being a purely rational enterprise of cognition and calculation, involves of necessity a non-formalisable, non-mechanisable, characteristically human phenomenon" (Smith B., 1988: 7).

One might call this phenomenon "judgement", "intuition," or, according to Polanyi, tacit or personal knowledge (Smith B., 1988: 7). Science is grounded on personal judgments. Accepted theories affect the interpretations of observations and their acceptance, or rejection, as observations (Prosch H., 1986: 89). Scientific knowing results from the integration of part to whole as in the case of perception. Current conceptions always affect the recognition (Polanyi M., 1972: 49). Theories, languages and interpretive framework are not abstract objects but

social formations tied to their practices (Smith B., 1988: 8-9).

Polanyi explains the work of tacit knowledge behinds the intellectual acts of induction and classification, especially in science. He states that there is no perception uninfluenced by our conceptual interpretations and no purely objective induction as it rests on our perception (Prosch H., 1986: 75-6). This accords with his central idea that all knowledge and exercises of skills are rooted in tacit knowledge. Identification of particular instances of kinds apparently does always entail a tacit dimension consisting of clues we cannot explicitly tell, but that we are aware of in the appearance of the object of our focal awareness (Prosch H., 1986: 80). That is,

“[It] only operates by making use of tacit dimension that depends on personal indwelling [of clues, such as theories] and not wholly explicit or objective operations” (Prosch H., 1986: 75-6).

Induction and classification make use of the same kind of integrative action that perception do, namely, a dwelling in an unspecifiable conglomeration of subsidiary clues we bring to bear upon the object of our focal attention (Polanyi M., 1969: 167). This process is based on a similar process as other performances of skills in: hammering a nail, the recognition of physiognomies, the mastery of tests, the use of tools, verbalisation of experience, and visual perception. “The powers of integration which achieve these acts have the same structure throughout” (Polanyi M., 1969: 169-70).

General empirical conceptions are abstract and featureless (Polanyi M., 1969: 168). In classification, the knowledge of key feature becomes a maxim for identification, but it is useful only to those who possess the art of applying it (Polanyi M., 1958: 261-4). All the clues provided by the particulars of that

instance, when dwelt in by a person, become integrated by him into a focal meaning into which all the instances he knows of become integrated when dwelt in by him as subsidiary clues to the formation of a focal class concept. Students in science would then learn to identify and classify entities by a master in order to acquire the tacit ability to do so correctly, a process which cannot be told in explicit terms (Polanyi M., 1964: 42-5). These operations have to be understood as skills in the same way as the bicycle rider or the swimmer (Polanyi M., 1969: 123-5).

Perception and inductive conception also influence each other in reciprocal fashion, as a continuous process. The conception of classes is built up from the integration of tacitly known instances of this class. The position reached can only have a personal character.<sup>7</sup> According to Polanyi,

“[This conception] continues to be built up or modified as experience unfolds ... by our continually noticing such instances” (Prosch H. (1986: 83). ... “The focus of each class of things, the concepts of which the class is composed, is somewhat modified every time a specimen is appraised ... to make them approximate more closely to what is normal for the species” (Polanyi M., 1958: 349).

They continue to reinforce and inform each other in the form they have achieved. They cannot be reduced to explicit marks, maxims or rules without personal appraisal (Prosch H., 1986: 83).

Scientific instruments work through explicit operationalism (Prosch H., 1986: 88). Working with them may be regarded as conducting abstract probe in forms of instrumentalised, explicit and quantitative knowledge. This process requires incorporating personal element into its use or creation. According to Polanyi,

“[W]e have to accredit it personally to acknowledge it to be trustworthy” (Prosch H., 1986: 76-7).

The way we dwell in this knowledge depends on tacit coefficients as the product of unspecifiable skills, not detached and objective information. They are meaningful only in terms of the particular theories, and the general notions about the nature of things that function as subsidiary clues dwelt in by the minds of those scientists who make use of these results (Prosch H., 1986: 89). “[The] theoretical knowledge fuses our subsidiary awareness of the particulars belonging to our subject matter with the ... background of our knowing” (Polanyi M., 1969: 134).

### **Problem-solving as a heuristic act**

Polanyi explains that problem-solving is a heuristic act. A heuristic power empowers us to identify novel solutions to novel problems. The heuristic act explains our adaptive capacity that it allows us to deal with novel experiences in a novel manner. It is a creative force that involves “seeing problems and reaching out to hidden possibilities for solving them,” whose success depends on our capacity for sensing the presence of yet unrevealed logical relations between conditions of the problem, background knowledge, and the unknown solution we are looking for (Polanyi M., 1957: 93). For “if all knowledge is explicit, ... we cannot know a problem or look for its solution” (Polanyi M., 1967b: 22). The problem-solving is a process achieved through an informal method without relying on definite rules as the last resort (Polanyi M., 1964: 21-3). It is an art that involves creating an effective tool for interpreting a new subject matter or solving new problems, whose mastery relies on an accumulation of concrete practical experience. This is what sets apart an expert from a novice. The

heuristic act, however, is different from a systematic operation: we could reach the solution by employing the latter, but without exercising any heuristic power.

The problem-solving process as the heuristic act involves an intelligent endeavour of “crossing a logical gap on the other side of which lies the unknown, fully marked out by our conception of it” (Polanyi M., 1957: 98) The width of the logical gap depends on a measure of ingenuity required for solving the problem. Our conception serves as a heuristic base to be modified every time we experience novel instances. The conceived solution is our projected vision to a reality. It is our focally formed conception of the solution of which we are subsidiarily aware of all the particulars.

The visions of problems, discoveries, classes, and performances, etc., result from our natural capacity for imagination and intuition (Polanyi M., 1964: 189). We exercise our intuition as we look at data as "clues" to the unknown solution; it serves us as “pointers to” and as “parts of” the solution as we "gain an intimation" of what the unknown solution may be or “the coherence of hitherto not comprehended particulars” (Polanyi M., 1985: 22). The intuition senses “the presence of a hidden reality toward which our clues are pointing” (Polanyi M., 1967b: 23-4). It is a product of a spontaneous integration in a specific surmise, which anticipates the presence of potential resources. The surmise refers to a heuristic probe or a hunch that narrows down an inquiry, but not as well-defined as a hypothesis or a formal solution, whose indeterminacy ranges between width of the original problem and specificity of the eventual solution (Polanyi M., 1968: 41).

The intuition stimulates the imagination in its pursuit of finding the

solution (Polanyi M., 1966: 91). The imagination, guided by the intuition, is a persistent, deliberate and transitive thrust at each inquiry that directs us to articulate ideas (Polanyi M., 1966: 9). When the intuition recognises validity of results, the imagination starts pointing to such possible manifestations as the conceived solution. The conception may be relatively evident as finding a misplaced object, or relatively obscure as solving a crossword puzzle. Forming the solution begins with setting out the problem in suitable symbols, reorganising its representation to reveal its suggestive aspects. We may come up with the conceived solution right after having recognised the problem, or by a tacit process of identifying from our memory any similar problem of which the solution is known.

As the intuition originates the imagination, the latter also induces the former. In succession, when we develop an interest in the problem (intuition), we begin to speculate about the possible solutions (imagination). And in so doing makes us more preoccupied with solving the problem (intuition).

Each chain of formal reasoning is supported by our tacit affirmation both at the beginning and at the end, where an articulation is “an instrument skillfully contrived by our inarticulate selves for the purpose of relying on it as our external guide,” a tool which disciplines and expands our capacity to reason (Polanyi M., 1957: 102). Practical realisation of the conceived solution takes a similar form. Active problem-solving steps involves the symbolic operations supported by our informal power. As a mathematician solves the mathematical problem by switching his focus between the intuition and formal computation, his interpretation of primitive terms and axioms, its expansion and re-interpretation are mainly an exercise of the inarticulate acts (Polanyi M., 1957:

102).

In a similar tone, the tacit or personal element is manifested:

“... in the scientist's skill in anticipating the consequences of given adjustments of his equipment or in seeing through or beyond established conceptual divisions; it is spontaneously to recognise the rightness of the pattern generated by some axiom or theory or taxonomy or in his capacity to distinguish what might be a highly subtle and hitherto unacknowledged type of order against a background of randomness” (Smith B., 1988: 7).

The solution that has been discovered at the cost of much effort and unsuccessful trials provides us with the additional intellectual power. This enables us to deal with the same situation in a routine manner in absence of any heuristic act and to perform faster decision-making. The situation once novel becomes a routine operation for the expert with the experience built-up over the years. “Good mathematicians are usually found capable of carrying out computations quickly and reliably, for unless they command this technique they may fail to make their ingenuity effective” (Polanyi M., 1957: 102). Although he may make more mistakes than the novice, he is able to quickly discover them, as though he had drawn “a portrait of his conceptually prefigured conclusions” (Polanyi M., 1957: 101).

### **Polanyi with Merleau-Ponty, Dilthey and Rothschild**

The following explain how Polanyi’s idea relates to other key thinkers in philosophy, notably Merleau-Ponty, Dilthey and Rothschild, whose works influence the thinking of Michael Polanyi. Merleau-Ponty’s work on mind and body foreshadows Polanyi’s idea on logic of tacit integration. His notion of "presence at the moment" and "carrying ourselves to the moment of experiencing," contribute to Polanyi’s view on embodied knowledge. Polanyi’s

idea of indwelling is substantially influenced by Dilthey's *lived experience*.

Rothschild's thinking also underlies Polanyi's idea on semiotic expression of tacit knowledge.

Merleau-Ponty argues our capacities to think and perceive are not separate, independent faculties. They are the mutually dependent aspects of psychological and physiological whole that embraces the subject's habits and skills who think and perceive (Merleau-Ponty M., 1962: 80). The body is not experienced as aggregation of its parts; rather it is in "undivided possession of this body through one's body image (body in the world)" (Jha S. R., 2002: 73-4). That is,

"Bodily spatiality is the development of one's bodily being, the way in which the body comes into being as a body." ... "The various parts of my body, its visual, tactile and motor aspects are not simply co-ordinated." ... "[All] movements are available to us in virtue of their common meaning. That is why, in their first attempts at grasping, children look, not at their hand, but at the object: the various parts of the body are known to us through their functional value only, and their co-ordination is not learnt" (Merleau-Ponty M., 1962: 149).

In understanding, "the apprehension of the whole makes possible and determines the interpretation of the particular part" (Hodges H. A., 1944: 135-6).

For Merleau-Ponty, what we perceive is "our presence at the moment when things, truths, values are constituted for us," whilst for Polanyi, it is past experience that performs as subsidiary clues during an integration by affecting what we perceive (Merleau-Ponty M., 1962: 71-2). According to Dilthey,

"[W]e start from the system of the whole, which given to us as living reality (der uns lebendig gegeben ist), to make the particular intelligible to ourselves in terms of it." ... "The fact that we live in the consciousness of the system of the whole is what enables us to understand a particular statement, gesture or action" (Hodges H. A., 1944: 135-6).

This relationship between part and whole constitute the gestalt perception:

his notion of the whole mind in apprehension, and the part, of which the whole makes the particular intelligible as in apprehending the meaning of an expression of a sign.

“[W]e understand by means of the co-operation of all the powers of the mind in apprehension. ... [W]e start from the system of the whole, which given to us as living reality ... to make the particular intelligible to ourselves in terms of it. The fact that we live in the consciousness of the system of the whole is what enables us to understand a particular statement, a particular gesture or a particular action. ... [T]he apprehension of the whole makes possible and determines the interpretation of the particular part” (Hodges H. A., 1944: 135-6).

The lived experience is also reflected in Merleau-Ponty’s mind-body integration, and Polanyi’s idea of integration in tacit knowing (Jha S. R., 2002: 79-80). The *lived experience* refers to inner states, process, and activities of which we are aware, whilst we concentrate on objective contents of consciousness (Hodges H. A., 1944: 158-60). “The experienced system of mental life must be grounded on the lived experience” (Hodges H. A., 1944: 135-6). Knowing is grounded in one’s body, which serve as a mean for action directed towards the meaningful world. This is a matter of connecting the person with his environment through body and mind as instruments; that is, “knowing as a presence at the moment” (Merleau-Ponty M., 1962: 71-2).

“The body is known to us through its functional value; its parts engaged in the performance of our actions are available to us in virtue of their common meaning” (Merleau-Ponty M., 1962: 149; Polanyi M., 1969: 222).

For Polanyi, these are embodied mind and integration of subsidiary clues directed towards focal object, which extends to use of tools and probe. We interact with the world by dwelling in our body and/or tools as instruments. To interpret environmental clues involves “skilful use of clues, a joining and mutual

adjustment of information from our sense organs about conditions inside and outside our bodies and from our memories” (Jha S. R., 2002: 72). Or with tools, “our subsidiary awareness of tools and probes can be regarded now as the act of making them form a part of our own body” (Polanyi M., 1958: 59).

In an integration, a person treats parts of body and/or tool in subsidiary fashion, or as potentialities.

“[W]hen put in front of scissors, needle and familiar tasks, [he] does not need to look of his hands and fingers because they are not objects to be discovered in space: bones, muscles and nerves, but potentialities already mobilised by the perception of scissors or needle, the central end of those “intentional threads” which link him to the objects given” (Merleau-Ponty M., 1962: 110).

The body and tools function as subsidiary clues—as potentialities—in an intentional act of integration. The body is “the *potentiality* that *surges toward objects to be grasped* and perceives them” (Merleau-Ponty M., 1962: 110).

Moreover, as we rely on our awareness of the first term for actively and intentionally attending for the second term in an integration, the notion of intentional action is an aspect of consciousness, something which is active in an unspecifiable sense (Merleau-Ponty M., 1962: 121). Intentionality is a pointing outward from the knower toward an object. This “active directedness” provides the starting point for Polanyi’s dynamic concept of tacit integration (Jha S. R., 2002: 121). Intentionality of the subject also allows for the “intersubjectivity,” which “enables the organisms to interpret the meaning of signs within inner communication systems as experiences, and eventually to express their meaning in forms created by the organism itself, culture and language, for instance” (Rothschild F. S., 1962: 778). It is this intentionality that bridges the meaning of signs and our experience both on receiving and sending messages.<sup>8</sup>

“*Understanding*” refers to both “apprehending the meaning of a portion of mental life” and “apprehending the meaning of an expression of a sign” (Hodges H. A., 1944: 158-60). “[T]he apprehension of mental states arises out of *lived experience* ... [where] the *whole mind* work together” in a systematic connection (Hodges H. A., 1944: 135-6). Any abstract thought—the explicit in mental life—needs to have tacit underpinning, in this case, the of the lived experience. The “*lived experience*” causes the interpretation of it in term of abstract thought. When we observe objects, we observe the conditions given to us by sensory impressions, and the relation of cause and effect arises through a synthesis from within us, by abstraction (Hodges H. A., 1944: 13-4). Without it, a person cannot convert the thought of a movement into actual movement by merely following explicit instruction (Merleau-Ponty M., 1962: 110). For Merleau-Ponty, this involves relationship to experience.

“The phonetic ‘gesture’ brings about, both for the speaking subject and for his hearers, a certain structural consciousness-ordination of experience, a certain modulation of existence, exactly as a pattern of my bodily behaviour endows the objects around me with a certain significance both for me and for others” (Merleau-Ponty M., 1962: 193).

The explicit, resulting from the lived experience, is interpreted afterward (after the understanding has taken place) by the abstract thought. In other words, this relation is a derivative of the living experience, intellectually interpreted afterward by abstract thought (Hodges H. A., 1944: 13-4). “We continually experience in terms of combinations and connections in ourselves, while we have to read combination and connection into the stimuli of sense” (Hodges H. A., 1944: 13-4).

Making-sense of articulated language involves personal accreditation.

Meaning-making is in context; the meaning maker is an inextricable part of this world (Jha S. R., 2002: 264).

"The link between the word and its living meaning is not an external link of association, the meaning inhabits the word, and language 'is not an external accompaniment to intellectual processes.' We are therefore led to recognize a gestural or existential significance in speech, as we have already said. Language certainly has an inner content, but this is not self-subsistent and self-conscious thought. ... [Our] body expresses meaning, but language does not express though ... It presents or rather it is the subject's taking up of a position in the world of his meanings" (Merleau-Ponty M., 1962: 193; Polanyi M., 1969: 222)<sup>9</sup>

Speech is not the 'sign' of thought. Speech and thought are not externally related, but are interrelated by the sense held within word (Merleau-Ponty M., 1962: 182). It is thus the "gestural and existential significance of speech" we recognise that lies beneath their conceptual meaning. "The process of expression, when it is successful, does not merely leave for the reader and the writer himself a kind of reminder, it brings the meaning into existence as a thing at the very heart of the text" (Merleau-Ponty M., 1962: 182). In Polanyi's term, sense-reading involves reception of message, deciding whether certain regularities should be taken to be significant. Sense-giving conveys, or reproduces, an experience for the purpose of communication. It refers to the verbalisation of an idea, memory, or the performance of a skill. Education, for example, is a consequence of consecutive integrations of these two processes (Polanyi M., 1985: 49).

Polanyi is not alone to address the tacit dimension in his epistemology. These thinkers supports his view on the wholeness of tacit knowledge. The view the "experienced system of mental life must be grounded on the *lived experience*" confirms the gestalt view (Hodges H. A., 1944). Since the whole is

greater than the sum of its parts, our apprehension of the whole makes possible and determines the interpretation of the parts. That our capacity to think, and perceive comes from psychological and physiological whole confirms the notion of embodied mind that knowing is grounded in one's body and mind. When we actively direct our undivided attention towards the focal object of integration, our body as *potentiality* allows us to dwell in them as instruments." This extends our physical exercise of skills to use of tools and probe, and our mind to abstract and interpersonal understanding.

## **2 – Critical Assessment of Michael Polanyi's Epistemology**

Polanyi's philosophy of knowledge is criticised on two grounds. The first asserts that personal knowledge is invalid—it is mere subjective and psychological phenomenon. The second argues there is the tacit knowledge, but in order to become meaningful and useful, it must be explicable. Addressing to these charges are critical because if there is only the articulated knowledge, or that the knowledge must fully become descriptive to be useful, then there is no room for experience in a heuristic process of learning and problem-solving. We perform these acts only by following rules. Beliefs, intuition, imagination, and ability to see a problem then become irrelevant. We are incapable of learning anything new, delivering novel solutions to problems, or solving non-routine problems.

There are four critics in this part. The first views tacit knowledge as psychological fact, and, as a result, become relative. The next view asserts that the tacit knowledge must be explicable. Perception and cognitive understanding are different kinds of tacit knowledge: there are different method to describe into

logical and analogical relations. Another view gives primacy to purpose and conception of skill, which necessitate exhaustive explicit statements to convey practice. Accordingly, Polanyi neglects the primacy of descriptive knowledge as being critical for performing action. The last view points to scientific knowledge. This is important because any practice that requires a degree of rigour in formal method can be considered along side scientific practice. The critic dismisses the role of scientist's experience and belief in practice of verifying scientific statement.

### **Tacit knowledge is subjective**

According to the first view, Polanyi's personal knowledge is a subjective entity as it is a psychological and relative phenomenon (Sanders A. F., 1988: 159). His epistemology relies too much on sensations as a mean to which one accesses the real entities (Mullins P., 1999: 48). The position and theory of the external world, which includes other knowing subjects, has no interdependence of the knower. As a result, a person possesses knowledge only in his mind.

Belief as a form of tacit knowledge is criticised under this category. The belief is a mean by which a person attempts to find means to reach at the objective truth. It is one of the subjective entity that results in knowledge being psychological and relative. To prove the objective truth by belief leads to the establishment of test statement, eventually leading to infinite regress of proofs. At certain arbitrary point he necessarily resorts to the subjectivism to stop the infinite regress at some privileged beliefs to guarantee or define the objective truth of what is believed (Musgrave A. E., 1968: 562-3). The person resorts to certain indubitable truths; some psychological attitude to justify reality. This

mental facts are supposed to guarantee truth or that the truth is identified with certain psychological state (Sanders A. F., 1989: 44). Some can go as far as to argue that man knows nothing: there is no belief to be called “knowledge.” There are only subjective beliefs or opinions (Musgrave A. E., 1968: 561-3). Knowledge merely becomes a representation in the mind of a particular knowing subject. Certain privileged beliefs are justified, which denies reality independent of human knower, and the scientific knowledge as real. This limitation on reality consequently results in relativism in the nature of knowledge that “no person can *prove* to the others who does not *share* his framework” (Musgrave A. E., 1968: 564).

To illustrate that belief and tacit knowledge in general are not subjective entity involves answering two questions. First, does Polanyi’s epistemology involve any attempt to settle questions of validity by considerations of psychological fact? Second, are men’s beliefs relativistic? That is, are they not on par with each other and there exists no objective standards? Are beliefs self-evident and incorrigible? Are they sharable among persons?

*1) Does Polanyi’s epistemology involve any attempt to settle questions of validity by considerations of psychological fact?*

The role of a subject is crucial in knowing process. Polanyi introduces psychological factors in his epistemology as methodologically relevant in the validation. Polanyi’s epistemology requires one’s own judgement in confirming validity of assertion, based on his background tacit knowledge (Prosch H., 1986: 220-1). However, one’s psychological property *never* guarantees truth nor can subjective theory justify truth.

Logical validity of a deduction of proof can be supported only by logical reasons, not psychological observations. Yet, the validity is not separated from psychological fact. It is the psychological fact that accounts for tacit knowledge of the knower. Polanyi equates psychological fact as belief, and as a form of personal knowledge, based on tacit dimension.

“... psychology may account for the factual conditions under which understanding and operation of logical reasoning may develop, and it may explain errors associated with it” (Polanyi M., 1958: 334).

The speaker’s point of view is equivalent to the belief that certain entity is true (Sanders A. F., 1989: 166-8).

“A person can speak of truth only with the universal intent in a position that sets against the rest of the public world” (Polanyi M., 1958: 334).

Beliefs are fallible. They only refer to the intended meaning (Sanders A. F., 1989: 215). A truth seeking person acknowledges the universal and ideal standards over himself as he holds himself responsible for the pursuit of knowledge (Polanyi M., 1958: 308). In other words, a person’s tacit knowledge is in constant interactions with the external world. Every person “has the possibility of exercising some measure of choice between degrees of conformity and dissent” (Polanyi M., 1958: 208). This results in beliefs held in the form of conceptual framework and the network of tacit integrations, both in forms of articulate manifestations and the inarticulate—tacit—coefficients.

One’s belief system derives from, and dependent on, the culture—language, traditions, and practices—within which one is born, brought up and educated. “Human body is the ultimate instrument of all our external knowledge,” the tacit know-how embodied in skilful performance, implicit

beliefs, stances and attitudes of the background function at an instrumental—subsidiary—level (Polanyi M., 1967b: 15) . This applies to learning, understanding, applying and modifying the articulate contents of the cultural systems (Sanders A. F., 1989: 180).

*2) Are men's beliefs relativistic? Are they not on par with each other and there exists no objective standards? Are beliefs self-evident and incorrigible? Are they sharable among persons?*

According to Polanyi, we constantly struggle to achieve objective knowledge. For instance,

“There is only one [universal] truth, though our [personal] knowledge is essentially incomplete and the truth is an unattainable ideal.”

The result is what believed is always opened to correction and improvement. Every person may believe something different to be true (Sanders A. F., 1989: 185-7). The possibility of error is a necessary element of any belief bearing on reality as the knowing process. Every factual assertion is capable of being mistaken and corrigible (Sanders A. F., 1989: 314-5).

Not all beliefs are refutable nor provable, though it does not mean they are subjective. “Proofs may conceivably be incomplete” (Polanyi M., 1958: 285). Some of them necessarily remain tacit. They cannot be rejected by a set of wholly explicit rules that seeks to reject them when any single explicit piece of evidence contradicts them or proved—logically derived—from facts of purely unbiased observation whether on theoretical or psychological grounds (as perceptual experience) (Sanders A. F., 1989: 195). Rules or theories are maxims, whose guiding function integrates into know-how, or practical knowledge

(Polanyi M., 1958: 50). The rules of an art never completely determine its practice, nor can they replace the know-how embodied in that practice (Sanders A. F., 1989: 194). The application of rules in weighting the evidence cannot be a matter of universal statute law. A decision can only be determined with considerable hindsight. One should stick to one's theories as long as it is reasonably possible (Sanders A. F., 1989: 191-5).

Thanks to the objectivity of language and human mental capacity, tacit coefficients are to some extent sharable. It is possible, but difficult, to intelligibly translate between different conceptual schemes: to understand, criticise and the like, whose process may be depicted as follows (Polanyi M. and Prosch H., 1975: 139-44).

“Against adverse evidence on one's conceptual schemes, one constantly reinforces a framework, suppresses the development of rival views and contributes to stability. Disparate schemes of interpretation can be criticised in the light of one's own local standards and ideals. The tasks of commitment as a mode of responsible and sincere belief is the openness to criticism, ... held in due consideration of evidence and of the fallibility of beliefs” (Polanyi M., 1964: 70).

People operating with conceptual schemes different from our own may act and argue completely intelligibly and rationally in terms of their view of the world (Sanders A. F., 1989: 20). A large-scale scheme of interpretation can be made possible as being sensible, stable, coherent and comprehensive, even though there is no guarantee of its bearing on truth (Sanders A. F., 1989: 20). It is a result of commitment to a particular approach as personal involvement in a particular cultural practice, but not to a set of specific propositions (Sanders A. F., 1989: 207). Therefore, different conceptual or cultural domains, which depend on their particular and relative internal standards, need not lead to

epistemological corollary that what is right is irredeemably relative (Sanders A. F., 1989: 209).

### **Different kinds of tacit knowledge**

To emphasise articulated form of knowledge, some writers go as far to call for different kinds of tacit knowledge (Harré R., 1977: 172-3). Harré argues the knowledge must be propositional and descriptive to be meaningful and valid.

The tacit knowledge must refer to:

“... the proposition which would describe that the knowledge we are able to bring it out, ... to reveal the tacit knowledge” (Harré R. (1977: 174-5).

That is, for the tacit knowledge to be validated as knowledge, it must be explicable. The knowledge remains tacit only because we voluntarily choose to attend to them subsidiarily in integration.

There is difference between two kinds of knowledge—perception and understanding (of theories, concepts and "knowledge-by-description"). The former refers to perceptual sensory elements of empirical experience, whilst the latter refers to theoretical or cognitive conditions of experience. Each requires different forms of subsidiary elements in integration. Perception is knowledge by acquaintance or experience, which is non-propositional, and, hence, not tacit knowledge. Its subsidiary term is the "object" of tacit knowledge. It is not the tacit knowledge unless it can be described. Both the subsidiary and focal elements are "that of which we cannot tell", not only because it is not propositional, but also because "one is not able to formulate propositionally that which is being known" (Harré R., 1977: 173).

Understanding of theories, concepts and "knowledge-by-description"

involves both proximal and distal terms that are propositional. The proximal consists of theories, understandings that are conceptual. We cannot tell the proximal only because we attend to it subsidiarily. Understanding meaning of a sentence or work of arts stands in-between the two forms (Harré R., 1977: 172). We attend from non-propositional perceptual knowledge to meaning, which is propositional. We attend, for example, from written or spoken words, or paintings, that are perceived, to the propositional meaning like a concept. We go from “perceptual items” to what is propositional (Harré R., 1977: 173).

Each form of tacit knowledge requires different methods to *reveal* subsidiary elements so that they qualify as tacit knowledge: i.e., by being descriptive. What is subsidiary in the case of perception is not properly called the tacit knowledge, until it becomes propositional and described. What matters is to reveal the tacit knowledge present in the “from-to” schema, by making clear in experience to describe what elements are subsidiary to the perception as a perceptual, psychological and analytical process. The subsidiary elements for the case of theoretical understanding are already the knowledge, since they themselves are propositional and related to knowledge by experience by logical and analogical relations. What is relevant involves exploring and revealing analogical interrelations among the components of theoretical knowledge we tacitly subscribe, by the use of analytical schema built around notion of multiple analogies, because the analysis of this of situation cannot be given in terms of the from-to schema.

To reveal all content of tacit knowledge contradicts Polanyi’s notion especially in the *Personal Knowledge* that all explicit knowledge; i.e., the propositional, descriptive knowledge, rests upon various kinds of non-critical,

pre-linguistic knowledge capacities. To regard, knowledge which can be described as the only valid form is to claim “we know only what we can tell,” rather than “we can know more than we can tell” (Polanyi M., 1967b: 4).

Revealing tacit elements we used subsidiarily by making them completely explicit is *not* what Polanyi tries to do. This is logically impossible as “we can know more than we can tell,” and we dwell in something else in a subsidiary way when we make anything explicit and focal (Polanyi M., 1967b: 4; Prosch H., 1986: 212). In fact, Polanyi recognises that many, not all, of the subsidiary elements involved in any instance of tacit knowing could be discovered (without disintegrating our central focal meaning beyond repair), and so become objects of our focal attention. Our knowledge is increased and expanded by a continual journey back and forth between analysis and synthesis. Nonetheless, it would be difficult to maintain that his overriding purpose in developing his theory of the subsidiary-focal distinction was that of rendering the tacit explicit” (Harré R., 1977: 175).<sup>10</sup>

Polanyi’s intention is to take both cases of perception and understanding as product of the “from-to” integration (subsidiary dwelling-in to focal meaning or comprehensive entity), established by our own imaginative and integrative capacities. He uses the case of perception to illustrate the same integrative process that underlies all forms of knowledge, including the cognitive understanding of experience, though the subsidiary content of each case is different.

Difference exists between what is meant to be “logical” for Polanyi and Harré. Harré’s logic accepts only explicit logic; i.e., formal rules of symbolic

logic in a way duplicable by explicit operationalism. “Everything our knowledge is based we can dig it out and focalise it” (Harré R., 1977: 175). In contrast, Polanyi is adamant that the “from-to” relation is a logical one, despite being tacit, and not merely a psychological explanation of the dynamics of theory construction (Prosch H., 1986: 214-5). What is logical is a ‘logic of tacit inference’ as “the way in which a mind dwelled in subsidiary clues to reach correctly a focal meaning across an explicitly logical gap” (Prosch H., 1986: 214-5). We need a mind to synthesise subsidiary elements into focal entity or meaning. We do so in perception, scientific discoveries, and in our justification of them.

There are many indeterminacies in our understanding of a proposition, which stand as grounds for our conclusions from it. We cannot render explicit our understanding of the ‘necessary conditions’ when it is that these are satisfied. We cannot reduce our need for a mind in making judgement to a complete, finite set of criteria. Yet, we do not make our judgements illogically, or alogically—only subjectively. They may or may not be sound, and correctly or incorrectly structured by us (Prosch H., 1986: 215-6). Our judgements have a logic, its function in correctly assessing what is implied by something else. It is the process of tacit inference: only can we acquire a tacit awareness of the correct rules, an awareness becomes implicitly more right as we become connoisseurs, resting upon many indeterminants, subsidiary elements we dwell. The same applies to analogy. What is involved is not simply noticing two things are the same, but determining they have a significant similarity, i.e., in respect to something. It is the product of many tacit notions and feelings, by reference to the complex of tacitly held notions we have in mind. They cannot be reduced to a

neat set of operational rules (Prosch H., 1986: 216).

### **Purposes and conception of Skills**

Since knowledge has to be explicable to be valid, in case of tacit knowledge of physical expression—a skilful performance—Jelfs questions Polanyi's nature and structure of skills (Jelfs B., 1982: 177-99). Jelfs also questions his analogical analysis between skills of swimming and bicycle riding and of science by asking if “mechanical and physiological process descriptions”—physiological events such as ‘regulating the respiration’ and ‘balancing’—“are identical to statements about a person’s knowing and awareness” (Jelfs B., 1982: 179-84).

In a skilful performance, as we focus on the whole (objects of focal awareness such as purposes), we are necessarily subsidiarily aware of the ‘skills’ through this process, according to the process of tacit integration (Jelfs B., 1982: 186-7). The focal awareness equates explicit knowledge, the “knowing that,” or description, of concepts, goals and purposes, whilst the subsidiary awareness corresponds to skills and tacit knowledge. The conception of a particular action is integral to the person performing that action.

“In performing action, are we not focusing on directing our efforts at such performance, rather than explicitly aware of knowledge—concept—of purposes, ... [which] is the object of our attention and it ‘runs ahead’ of our action?” (Jelfs B., 1982: 186-7)

This is evident as, an example:

“The conception of a Sonata pianist has will enter into what he does when he plays the musical score” (Jelfs B., 1982: 186).

This necessitates exhaustive explicit statements that sufficiently convey

practice. The importance is the way we employ language in describing human activities relates to the notion of tacit integration. Language is the only vital element in the tacit integration, as evidenced in the following,

“The connoisseurship can [only] be communicated by precept” (Jelfs B., 1982: 192-3).

Polanyi neglects the role of descriptive knowledge in our performing action, though description of action in our memory constitutes to a crucial part of the integration. These concepts fail to be mentioned in an act of problem solving, as he “did not give attention to those concepts we ordinarily associate with descriptions and explanations of action” (Jelfs B., 1982: 190). For instance, Polanyi does not provide any example of the criteria or reasons in making judgements about the skills.

“[He] fails to notice” ... “that in evaluating a pianist’s performance as ‘skilful’, the employment of a criterion such as ‘touch’ does not permit Polanyi to ask about the existence of ‘touch’ as if it were some property or particular movement of the pianist’s hands” (Jelfs B., 1982: 185).

This is equivalent to asking in what respect does Polanyi’s analysis of skill provide an intelligible answer to the question of “What did he do?” (Jelfs B., 1982: 186). Moreover, the unspecifiability and inexplicability of particulars or skills, though some can be made aware, eventually lead to the notion that “nothing could be said and no question could be asked,” thus, viewing tacit knowledge as subjective entity (Jelfs B., 1982: 195-6).

However, concepts and descriptions are, to Polanyi, “maxims,” or explicit rules of action. As they only serve as a guide to perform action correctly, they do not necessarily lead to successful performance. Memory is particulars–subsidiary clues—we rely on in problem solving. Language, which allows for production of

descriptive knowledge, is an articulated product of shared culture based on the tacit co-efficient, which enables communication and common understandings among people.

### **Scientific objective knowledge**

Scientific objective knowledge must be independent of personal and psychological facts to be valid. The objective knowledge includes theoretical and explicit knowledge, whilst the personal and psychological knowledge conforms with the subjective knowledge. Logical contribution of science and psychological contribution of scientists are separate entities (Musgrave A. E., 1974: 567-8). That is,

“A scientist analyses and evaluates contributions to science independently of personal or psychological facts about the scientist who produce it, or ... anybody else” (Musgrave A. E., 1974: 568).

Truth of a statement is not established by experience nor belief. It is only justified by objective and logical analysis, which concerns with logical or objective features. This involves truth and falsehood, deducibility, contradictoriness, deductive explanation, explanatory power or empirical content, simplicity and verisimilitude (Musgrave A. E., 1974: 573). That is,

“The objective standards in the light of which critical appraisal of that knowledge may take place ... are interpersonal or impersonal ones” (Musgrave A. E., 1974: 570).

To prove a theory, scientists only work at the level of formal and explicit knowledge. They constantly operate with “theories”:

“They constantly ‘accept’ or ‘choose’ or ‘prefer’ one theory over some others ... and they may use the degrees of corroboration of the various theories to guide their choices” (Musgrave A. E., 1974: 854).

The truth consists of “those easily testable experimental statements about whose truth or falsehood the community of scientists happens to agree at some time” (Musgrave A. E., 1974: 568). “Statements can be justified only by other scientifically accepted statements; the truth of an observation statement cannot be established by appealing to the psychological fact that you have had certain perceptual experiences” (Musgrave A. E., 1974: 568).

Working at the theoretical level involves the use of language to create a body of objective knowledge. This, in Popper’s term, is the “*third world* of the objective knowledge” produced by linguistic behaviour to produce descriptions and arguments (Musgrave A. E., 1974: 586). The language is an explication of the subjective knowledge. The objective feature of language (based on the subject’s personal knowledge) is distinct from the objective knowledge (in theories or scientific knowledge). The language reflects human knowledge as approached from the point of view of the subject who produces it. In this regard, Popper is consistent with Polanyi on the crucial role of the person in the knowing process. However, this process only operates at the articulated level as in the case of language, not at the tacit level in Polanyi’s. The knowing subject, as an autonomous entity, expands his knowledge by constant feedback with the objective knowledge. The growth of knowledge depends on the activities of human subjects as long as they who produce it recognise its objective aspects, and utilise them as common standards they conform (Musgrave A. E., 1974: 587).

The capability of an explanation which conforms to them does not depend on any personal or psychological facts. Popper refuses as reasonable the belief that a theory is true, and the *commitment* to the truth of a theory (Musgrave A.

E., 1974: 583). Instead,

“the scientist need not believe; [they merely] need to ... choose a theory as the best one available” (Musgrave A. E., 1974: 583).

It is not rational to believe that a theory is true when we can never prove it (Musgrave A. E., 1974: 583). A scientist proposes an autonomous and impersonal structure when he purposes an explanation or seeks to explain in the objective sense of that term. Others who try to assess this contribution would do so in the light of objective or impersonal standards.

Psychological factor merely serves as motivator to pursuit of knowledge that itself alone bears no relationship to reality. The commitment as a psychological attitude plays minor roles only to motivate scientists, but not to guarantee results they may obtain from an experiment. Further, there are risks of subjectivism attached to the psychological factor that

“[A]n experimenter may be motivated by a dogmatic commitment to some theory. ... [T]he public argumentative status of an experimental investigation is independent of the private psychological motivation for undertaking it. Private motivations are therefore less important than they might appear to be” (Musgrave A. E., 1974: 583).

The question is whether the objective knowledge and psychological factor are two completely distinct processes. Is Polanyi's personal and tacit coefficient merely a psychological factor and thus should be eliminated? Popper gives clear distinction between the objective and psychological/subjective knowledge and proposes a third world of the objective knowledge based on the subject's point of view to produce and describe the real objective knowledge. The knowledge from the subject's perspective in Polanyi's term, however, is the personal knowledge. The personal knowledge is distinct from the knowledge as in Popper's third

world of the objective knowledge purely based on language and description. One cannot divorce from the tacit element in the personal knowledge. As stated above, one's belief system is derived from his background knowledge.

Therefore, Popper's account of objective scientific knowledge neglects the "states of mind" among scientists (Musgrave A. E., 1974: 575). According to Polanyi, even the scientific knowledge cannot be the "epistemology with a knowing subject" (Musgrave A. E., 1974: 576).

Tacit knowledge is indispensable in all cases. Even though tacit knowledge is inseparable from psychological fact, there is universal objective standard over the tacit knowledge as we interact with the external world. As a result, personal beliefs are prone to error. Since the tacit knowledge rests on non-critical and pre-linguistic knowledge capacities, it is logically impossible to reveal all elements that form subsidiary parts of the tacit knowledge. Moreover, there are same imaginative and integrative capacities underly exercise of all knowledge. Also, as Polanyi stresses the importance of descriptive knowledge only as good as a guide or rules of action; i.e., maxim, the description alone is far from sufficient for delivering successful performance. In science, though it relies on formal method for verifying scientific statements, scientists' exercise of scientific judgement operates from their own experience that is prone to error. For Polanyi, scientific knowledge does not differ from the tacit knowledge.

### **Conclusion**

The first section explained the core idea of Michael Polanyi's philosophy of tacit knowledge that all exercises of knowledge and skill were rooted in a tacit dimension. It illustrated an informal process of a tacit integration of clues. It then

contributed classification of skills based on their explicit expressions—into the physical, semiotic and intellectual—to an understanding of how his thought may be applied. The chapter also identified the tacit knowledge as closely related to experience. Problem-solving is a heuristic act, which enables us to deal with a novel situation in a novel manner. It is essentially tacit, despite an interplay between the articulate and the inarticulate. A problem-solving capability is positively related to a level of experience, an accumulation of which forms a repertoire of portmanteau reactions as behaviour patterns, which immediately became part of appropriate routes toward a solution. It transforms once the novel situation to a routine operation in eyes of an expert; his experience is transformed into a wealth of resource ready to deal with occurrences with increasing subtlety. He possesses the superior problem-solving skill compared to a novice. Although the expert may be as prone to making mistakes as other relatively inexperienced person, he is better able at identifying and rectifying errors. His problem-solving approach becomes increasingly non-routine, adaptive and does not follow a strictly logical pattern. A close inspection reveals an ability to improvise: to make a quick and reliable decision without prior stipulation (Weick E., 1998: 544). It is a process where by a fresh contingency is mixed with previously learnt lessons, guided by patterns discovered retrospectively (Berliner P., 1994: 546-7). We are said to improvise as we thrust our intuition-guided efforts towards problem solving in an extemporaneous fashion.

The section also explained how Polanyi's philosophy was influenced by others, notably Merleau-Ponty, Dilthey, and Rothschild. Merleau-Ponty's and Dilthey's philosophy provided several grounds for Polanyi's philosophy; most notably on a gestalt view of the tacit knowledge and instrumental involvement of

body and mind. This explained extension of physical exercise of skills to use of tools and probe, and exercise of mind to abstract and interpersonal understanding. Rothschild provided Polanyi with the notion of bodily involvement in the interpersonal communication process.

The second section contributed to a general debate on Michael Polanyi's philosophy by reviewing his critics and presenting defence. The arguments here were based on surrounding philosophical literature. Critics who dismissed a personal coefficient in beliefs, experience, and scientific practice as valid or necessary were evident in the work of Karl Popper and Alan Musgrave. Another view placed primacy on the explicit knowledge, such as that of Rom Harré and Brian Jelfs. Harré viewed perception and cognition as two distinct processes of the tacit integration and claimed the tacit knowledge was only valid providing what we knew could be cognitively and theoretically described. Jelfs asserted on the necessary explication of the subsidiary and focal clues in the act of integration. Their implications are important. For without the tacit knowledge, there is no room for the heuristic process. However, it was clearly illustrated it was impossible to deny a presence of the tacit knowledge. The personal knowledge was as inseparable from psychological fact as it was impossible to fully reveal its elements and process. There was a universal objective standard, which made the personal knowledge fallible. And despite a utility of the descriptive knowledge as a guide or a rule of action, it is far from being sufficient for mobilising a skilful performance. Even a formal method of verifying scientific statements still involves exercises of scientists' personal experience and belief.

Notwithstanding, our focus on Polanyi literature was limited only to

relevant aspects of this research and could not represent a complete review and critics of Michael Polanyi's philosophy. Polanyi also authored substantial amount of work, to name but a few, in arts, politics, and religion. Similarly, this is not to say those thinkers who influence Polanyi's idea are limited to a number of scholars discussed above, for they are the most influential to Polanyi's idea presented in this chapter.<sup>11</sup>

It is suffice to confirm the tacit knowledge is central to *all* kinds of skilful performance. Michael Polanyi's philosophy of tacit knowledge is philosophically valid and provides sufficient ground for an interpretation of a real-world phenomenon.

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<sup>1</sup> See, for example, Collins H. (1993), Cook S. D. C. and Brown J. S. (1999), Lam A. (2000).

<sup>2</sup> For studies on the impact of technology on work process, see, for example, Adler P. (1992); Attewell P. (1987); Cockburn C. (1993); Hodson R. (1988); Hirschhorn L. (1984); Zuboff S. (1988).

<sup>3</sup> This is termed "the spiral of knowledge creation" (Nonaka and Takeuchi, 1995). However, this view is subject to some criticisms. See, for example, Spender J-C (1993, 2007 and 2008) and Tsoukas M. (2005).

<sup>4</sup> He points further that "complex higher order actions are executed by being broken down into constituent, relative routine tasks, each of which may be performed without thought or conscious reflection. Given higher order action is then itself able to be carried out more or less automatically in virtues of the fact that the objects whose successive realisation is aimed at in the given constituent micro-actions have become, in different ways, stamped with value in their own right.

<sup>5</sup> Polanyi explains further the structure of tacit knowledge that the focal object then becomes subsidiary to the next integration. Levels of knowing are stacked on top of one another in such a way that the focal object of the first level becomes the subsidiary to the next. He terms this property as the 'ontological hierarchies' of tacit knowledge. This is evident in his example of 'latent learning' or 'partial solutions' and 'past experience' shown below.

<sup>6</sup> Past experience is a form of the marginal clues: they are our previous meaningful integration of clues we have become used to seeing in the past.

<sup>7</sup> This corresponds to Polanyi's view of the ontological hierarchy of knowledge

<sup>8</sup> According to Rothschild, the intra-organismic information/semiotic systems consist of 1) semantics—the relation of signs to their meaning; 2) syntax—the

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physical form of signs and rules of their arrangement; and 3) pragmatics—the concrete communication process. There are rules of the syntax of each communication: the biological and linguistic, for simultaneous utilisation of different communication systems. If these rules are not followed, the consequences are meaninglessness, or the misinterpretations of signals.; See Rothschild F. S. (1962: 781) and Polanyi M. (1969: 222) for an investigation of how the communication process of life that convey meaning in analogy to semiotics of language supports Polanyi's conception of theory of meaning and indwelling in a biological and objective way.

<sup>9</sup> Merleau-Ponty (1962: 193) defines the term 'world' not as "a manner of speaking," rather, "it means that the 'mental' or cultural life borrows its structures from natural life and that the thinking subject must have its basis in the subject incarnate. The phonetic 'gesture' brings about, both for the speaking subject and for his hearers, a certain structural co-ordination of experience, a certain modulation of existence, exactly as a pattern of my bodily behaviour endows the objects around me with a certain significance both for me and for others."

<sup>10</sup> This is "the device by which tacit knowledge could be systematically explored, though not exhausted." See Harré R. (1977: 175), Polanyi M. (1968: 1311), and Polanyi M. (1961b: 237-47)

<sup>11</sup> Other researchers who wish to review Polanyi's thought from an alternative perspective would soon discover his idea were related to a greater sphere of authors.

## **Chapter 3: Methodology**

### **Introduction**

This chapter outlines research methodology to a study tacit knowledge that is consistent with Michael Polanyi's philosophy of knowledge. The chapter proposes that a study of tacit knowledge be approached by the study of experience.

The first section explains how the interpretive method makes it possible to understand the meaning of others' experience. The aim is to take the subject's perspective, by projecting oneself into the experience of others and getting as close as possible to seeing the other's experience from their point of view. It also proposes that the qualitative research methods employing "human instrument" allows the researcher to describe experience from a first-person view based on his experiential and propositional knowledge (Lincoln Y. S. and Guba E. G., 1985: 187-9).

The section that follows proposes that "thick description" is an appropriate method to capture in detail the tacit knowledge embedded with the phenomenon. To generate thick description is to create interpretive structure by capturing and determining subjects' multiple meanings attributed to their actions and their own interpretations in problematic situations.

The subsequent part deals with data collection. Both the knowledge that experience and description contribute to the researcher's understanding of the phenomenon. This research thus comprises both secondary and primary research. Consistent with thick description, identifying situation for research interest involves critical incident technique. Key to an in-depth understanding of the

critical incidents involves securing multiple narratives from interviews and observation, collecting instances of interactions, and reviewing existing literature. To interpret meaningful experience requires the study of recurring terms, and the experiential units. Active coding and categorising is the process of creating interpretive structure that establishes linkages and connections of meanings. Triangulated sources of data, research method and verisimilitude of the thick description addresses the issue of validity of this interpretive research.

### **1 – Interpretive research and tacit knowledge**

This study asks a question of how tacit knowledge is exercised and what knowledge is embedded when people, as an individual or as a group, perform action. It addresses the “how” question by interpreting a relevant set of experience from within. Since people attribute meaning to events and environments, this research needs a methodology that focuses primarily on the human interpretations and meanings, allowing the researcher to view events and the social world through eyes of the people he studies (Bryman A. and Bell., 2003: 93). The interpretive research produces meaningful description and interpretation of how certain conditions come into experience and persist (Denzin N. K., 1989: 23).

A process of interpreting, knowing and comprehending meaning of experience, lays a groundwork for understanding (Denzin N. K., 1989: 62) The meaning refers to a signification, purpose and sequences of the set of experience (Denzin N. K., 1989: 104). To interpret is to explain the meaning of a term; it is to set forth, or clarify, the meaning of an experience or event. Since people create and maintain meaningful worlds through dialectical processes of conferring the

meaning on their realities and acting within them, the interpretation brings out “the meaning embedded in a text or slice of interaction” (Ricoeur P., 1979: 96).

To interpret a phenomenon is to look for similarities and compare differences: it is the work of thought, which consists in “deciphering hidden meaning in the apparent meaning“ (Ricoeur P., 1974: 13). It clarifies the meaning that is “felt, intended, and expressed by another” by “the description of another person’s action within a framework that is meaningful to that person” (Denzin N. K., 1989: 104). A researcher “makes recognisable visible slice of human experience that has been captured” (Denzin N. K., 1989: 26). To investigate, make visible and interpret how the others interpret and make sense of what happens to them is equivalent to asking what people really say when they say something, or what they really do when they do things. The interpretation focuses on understanding human meaning-making where the issue of causality must be contextualised (Schwartz-Shea P., 2004: 12-3). Categories, concepts, and theoretical level of an analysis emerge from the researcher’s interaction within the field and questions about data (Charmaz K., 2000: 521).

In an interpretive study, truth depends on perspective taken (Sandberg J., 1995: 156-64). Meaning is embedded in an expression of experience in interactive situation. This involves an interaction between (1) people; (2) objects, events, or processes; and (3) actions taken toward those objects, events or processes (Denzin N. K., 1989: 104-9; Blumer, 1969: 9). The meaning is obtained by projecting oneself into the experience of others, i.e., seeing their experience from their point of view. The researcher becomes a reflective subject who can tell his and the others’ stories (Denzin N. K., 1989: 81, 121). Since tacit dimension of knowledge resides with the experience, to study it is to take the

subject's perspective on the issue (Denzin N. K., 1989: 111). The tacit knowledge is situational, context-dependent and expressed through people's experience of work. It is grounded in the "lived experience."<sup>1</sup> They possess the Polanyi's tacit dimension (Sandberg J., 2000: 12).

Since people inextricably relate to the world through their lived experience, the way it supports apprehension is consistent with Polanyi's notion of past experience in an integrative act (Sandberg J., 2000: 4, 7). Primary focus of an interpretive method is on meaning structure of the lived experience; i.e., an aspect of reality people assume or "people's ways of experiencing or making sense of the world" (Sandberg J., 2000: 12). To study experience from within is to capture the "lived experience" of the subject, and to produce meaningful descriptions and interpretations of how certain conditions come into existence and persist.

### **The hermeneutic process of studying meaning**

To explore human experience requires a method that describes the experience as it is "lived" or emerged from contexts from a first-person perspective. The world of lived experience does not always correspond with the world of objective description since events cannot be explained separately from its context. "Experts live their knowledge in a way that is not fully representable by a set of decontextualised rules and statements" (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 135-6) His professional experience enables him to anticipate an event differently from others (Lincoln Y. S. and Guba E. G., 1985: 196) "Since reality constructions cannot be separated from the lived-world in which they are experienced, the meaning of an experience is always situated in

the current experiential context and is coherently related to the ongoing project of the life world” (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 135-6). The experience is personal knowledge: “[it] cannot be located “inside” the person as complete subjectivity nor “outside” the person as subject-free objectivity” (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 136). To explore the meaning is to apprehend a pattern as it emerges by relating descriptions of specific experiences to each other to the overall context of the life world (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 137).

Tacit knowledge functions against a practical background that is transparent to native users. “Experience is conceptualised as dynamic process in which certain events become figural (standout) in the individual’s life-world while others recede into background” (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 136). The background knowledge is a human construction. It is a product of their everyday coping with the world, which incorporates “a history of experience, consolidated habits and structural repertoires,” that provide successful responses to difficult situations. It serves as both sources and outcomes of the knowing activity. The background knowledge has to be made accessible to an inquirer.

A “human instrument” is required for a study of meaning, as a tool to take the meaning from subjects and context of a phenomenon. The human instrument refers to normal human activities such as reading, listening, speaking and looking that builds upon researcher’s propositional and tacit knowledge. Its extension towards studying documents or records, interviewing, observing unobtrusive clues is more consistent with a qualitative methodology (Lincoln Y. S. and Guba E. G., 1985: 198-9).<sup>2</sup> Its unchangeable nature provides potentiality for the

researcher to learn unexpected things, for example, in observing informants' choice of behaviours (Yow V. R., 1994: 7). The researcher's own world of experience is a proper subject matter of inquiry. His experience in the social world contributes to an understanding of an expression of its emergent properties and features (Denzin N. K., 1989: 25).

This approach allows the researcher to grasp the subjects' underlying conceptual theories of interpretation or conceptual structures (Denzin N. K., 1989: 20-1). He captures multiple meanings and contradictions through subject's expression of experience (Denzin N. K., 1989: 24-5). The expression of meaning of the experience is given in symbolically meaningful ways as narratives and slices of interactions. The study of meaning behind human action is based on a symbolic realm , which relates to that meaningful action. This is based on the study of the expression, and interpretation of subjective human experience (Denzin N. K., 1989: 24). This is the study of how events and situations are interpreted through an individual "sense-making" process (Prasad P., 1993: 1404).

Since human subjects know more than they can say, they may not be fully aware of taken-for-granted assumptions underlying their meaning-making activities. Attuning to this meaning-making involves sensitivity to ambiguity. The researcher investigates efforts to promulgate or resist particular meanings as well as the variation of meanings across context (Polanyi M., 1967: 4; Schwartz-Shea P., 2004: 12-3). *All* forms of data reflect and encode human practice, though much of it is articulated as in interviews, documents, and field notes. Because people convey as much tacitly as they do through words, information a sender and receiver respond without the propositional knowledge are nonverbal

cues obtained from unobtrusive measures. We make inferences into the tacit meaning by examining the context in addition to text by getting as close as possible to the subjects who possess and actively use the knowledge (Hansen H., 2006: 1055; Denzin N. K., 1989: 20-1). To empirically research requires some degree of the experiential, or tacit, knowledge of an entity of interest—including person, place, thing, or process—through “sustained acquaintance” of the researcher (Heron J., 1981: 27). Meanings conveyed by words, phrases and gestures are grasped and understood, through participation into the context, producing interpretation through research experience that seeks to capture understanding of a sense-making process (Denzin N. K., 1989: 126; Hansen H., 2006: 1056).

Since understanding is grounded in tacit knowing, the researcher’s own tacit knowledge “intrudes into every inquiry whether or not the investigator recognises that fact or [is] willing to own it” (Lincoln Y. S. and Guba E. G., 1985: 197). Every researcher brings along his preconceptions and interpretations (Heidegger M., 1962; Gadamer H. G., 1975; Denzin N. K., 1989: 23, 43). Pre-understanding is a resource for fieldwork that covers knowledge, insights and personal experience, as essential elements in collecting and analysing information. It refers to both the knowledge of theories and social patterns. The former includes concepts, models, and approaches that help us “identify, diagnose, define, and analyse major factors and relationships” or “to provide structure to a given situation and convey this understanding to others” (Gummesson E., 1995: 63-4). The latter is based on the experience that helps the researcher develop receptivity to signals to social environment and behaviour patterns, enabling him to interpret, for example, the “silence at the meeting”

(Gummesson E., 1995: 67) In addition, the “interpretation must engulf what is learnt about the phenomenon and incorporate prior understanding while always remaining incomplete and unfinished.”<sup>3</sup> Spending time in the field is the only mean to develop his acquaintance of social patterns (Gummesson E., 1995: 64-5).

The researcher develops his understanding directly from his own experience and indirectly from experience of others through knowledge by description—intermediaries such as textbooks, or research papers. Prior understanding include background information and knowledge on a subject, concepts, hypotheses, and propositions contained in research literature, previously acquired information about the subject and his direct experience. How one judges the phenomenon from the outset of an investigation also contributes to the prior understanding. “[B]ecause prior understandings shape what is seen, heard, written about, and interpreted ... [they] are part of what is interpreted” (Denzin N. K., 1989: 63-5). However, knowledge gained from research mainly by description poses a weakness. Although the descriptive knowledge enables us to transcend limit of private experience, it carries greater risks of false information and misunderstanding. A comprehensive and rich piece of the descriptive knowledge still cannot replace the direct experiential knowledge. Studies of literature provide an opportunity for understanding, but they are subject to diminishing marginal utility without the knowledge gained from the experience (Gummesson E., 1995: 59-60, 70).

Notwithstanding, the value of fieldwork is positively related to researcher’s level of prior knowledge. Greater understanding permits better use of concepts and theories in data collection. The foreknowledge endows him with receptivity

to signals, a propensity to perceive parts of reality, analyse and interpret others' experience (Gummesson E., 1995: 56). The more he engages with fieldwork, the greater repository of tacit knowledge he accumulates through data obtained from his human instrument. This is a hermeneutic circle as "an iterative process whereby each stage of our research provides us with knowledge. ... [W]e take a different level of pre-understanding to each stage of the research" (Gummesson E., 1995: 61; Denzin N. K., 1989: 22). A research conclusion necessarily rests on the researcher's experiential and practical knowledge of the subject of inquiry. This experiential knowledge becomes an empirical foundation where the presentational construction is based. The tacit knowledge is a base a human instrument builds many of the insights and hypotheses that eventually develop, and are to be cast in propositional form (Lincoln Y. S. and Guba E. G., 1985: 198). This is possible only when the researcher and the subject are fully present to each other in a relationship of reciprocal and open inquiry when each is open to construe how the other manifests (Heron J., 1981: 31). The tacit knowledge must then be converted to the explicit knowledge in order to be reported propositionally (Lincoln Y. S. and Guba E. G., 1985: 198).

## **2 – Thick description**

The phenomenon, once captured, is illuminated in a thickly contextualised manner. The thickly descriptive method employs the human instruments to secure meaning embedded in an expression of experience to reveal its features. Here we describe meaning of the thick description and methodology apposite to an inquiry of tacit knowledge (Denzin N. K., 1989: 30).

The thick description is a method to infer a relationship between an action

and a socially established structure of meaning as a way people do things (Geertz C., 1973: 12). It approaches an interpretation “from the direction of exceedingly extended acquaintances with extremely small matters” (Geertz C., 1973: 21). The thick description describes the world as “a web of references”—or “web of signification”—through:

“... a reference game of something referring to something else that relationships are constructed, pictures emerge from backgrounds, and small matters speak to grand realities, ... [by [a]] establishing linkages and connections within situations and between situations [and [b]] creating a perspective by locating action in space and time [i.e., context] ... [c] bringing observed phenomenon to life ... through sequencing and punctuating events. ... Generating the thick description is to weave the web of signification as a process of creating interpretive structures” (Patriotta G., 2004: 58).

The thickly descriptive method establishes significance of an experience and sequence of events” (Denzin N. K., 1989: 83-4). It provides context of an act by stating intention and meaning, which organise that action, tracing its evolution and development, and presents the action as text (Denzin N. K., 1989: 32). It attempts to rescue and secure meanings, actions, and feelings that are present in an interactional experience by capturing and determining the meaning of “the actual flow of experience of individuals and collectivities in a social situation” (Geertz C., 1973: 20; Denzin N. K., 1989: 101-2). Moreover, it uncovers the meaning that informs and structures such experiences by capturing “the interpretations persons bring to the events” (Denzin N. K., 1989: 52, 116, 118). The thick description aims at uncovering “conceptual structures that inform the subject’s acts” or “theories often told in form of stories, that structure the experiences of the persons,” by allowing the reader to “experience vicariously the essential features of the experiences” being described and interpreted (Geertz

C., 1973: 18; Denzin N. K., 1989: 101-2).

Thick description produces truth-like statements of actions. It provides a rich holistic picture of broader phenomena in which small fact is inscribed by presenting detail, context, and the webs of social relationships that join persons to one another (Patriotta G., 2004: 77). This *verisimilitude* rests on the researcher's ability to clarify what goes on within the community of study, producing for readers the feeling that they have experienced, or could experience, described events that could be confirmed and substantiated (Patriotta G., 2004: 76; Denzin N. K., 1989: 100, 140). The thickly contextualised description encourages embodiment of tacit knowledge to the readers: it helps them "adopt a broader, more systemic frame of reference" (Folger R. and Turillo C. J., 1999: 746). It encourages a "heuristic embodiment" on both the researcher and reader, providing an access to the tacit knowledge and experience. It is a "depth examination of an instance"—e.g., issues and events—that presents "a holistic and lifelike description ... that the readers normally encounter in their experiencing of the world, rather than being mere symbolic abstractions of such" (Lincoln Y. S. and Guba E. G., 1985: 359-60). The tacit knowledge once assessed encourages vicarious participation—the vicarious experience—into the scenario in question, recalling actual events or imagining variations on them (Folger R. and Turillo C. J., 1999: 747).

Revealing the tacit knowledge involves capturing the meanings and experiences of interacting individuals at problematic situations. It works to the conditions that move them to take or experience actions, and their conclusion (Denzin N. K., 1989: 20-1). Cognitive dimension of tacit knowledge is made explicit at these problematic situations. Focusing on particular slices of

problematic experience contributes to an understanding of how people frame and solve problems within context (Barzelay M., 1993: 310-1). There are several ways to generate a thick description, though the good one need not incorporate all the following aspects. It may “focus on the slice of interaction, experience or action and records its occurrence in thick detail,” describing in detail a person in a situation or phenomenon or interactions among individuals. These slice contain “dialogue and interaction, taking the reader into the situation and tell how the subject reacts to the situation, connecting a turning point experience to its moments of occurrence.” Alternatively, the thick description may focus on the reconstructed account of individual’s prior experience, or relationship among them. It connects them to the situation by presenting it “in terms of the point of view of the persons being studied ... [by allowing] entry into the situation of experience” by re-creating the “sights, sounds, and feelings of persons and places.” It records interpretations that occur within the experience as it is lived, by having the subject reflecting on “their experience as it occurs” (Denzin N. K., 1989: 95-8).

The thick description mobilises multiple triangulated methods at the problematic situation that reveals a turning point experience uncovering what has been taken for granted. The fundamental is researcher’s thorough understanding of the phenomenon. His knowledge is developed directly from experiential understanding or indirectly from experience of others. It is critical that the researcher gains prior understanding of the phenomenon by researching into an existing body of literature. This precedes an ability to identify the problematic situation. The research applied the critical incident technique as a classification method to facilitate an investigation of significant occurrences. Then, the in-

depth technique employed qualitative in-depth interview and observation to capture expression of experience from narratives and field-notes (Denzin N. K., 1989: 62; Prasad P., 1993: 1404).

### **Secondary research**

An interpretation requires the researcher to do “everything within his power to make himself informed. ... by making [his] mind the repository of the (potential) responses a given text might call out” (Fish S. E., 1980: 48-9). Prior understanding include background information and knowledge on subjects, concepts, hypotheses, propositions contained in research literature, and previously acquired information about the subjects and their experience. “[B]ecause prior understanding shapes what is seen, heard, written about, and interpreted.” It is a part interpretation. It affects how one judges the phenomenon at the outset of an investigation (Denzin N. K., 1989: 63-5).

The preliminary research refers to a secondary research that involves critical analysis and interpretation of prior studies (Denzin N. K., 1989: 7). The researcher performs critical reviews of prior literature how it has been presented, studied and analysed (Heidegger M., 1962: 23). The aim is to lay bare prior conceptions of the phenomenon in question, how it has been defined, observed and analysed. It then critically reviews prior definitions, observations and analysis to reveal preconception surrounding existing understanding (Denzin N. K., 1989: 51).

### **Focus on narratives**

A study of narratives is pertinent to the study of tacit knowledge. Narratives are sense-making device of the narrator. Experience is articulated

through the narratives. They “allow actors to articulate knowledge through discourse, and ... [allow] access to tacit stocks of knowledge that have been externalised in a text-like form” (Patriotta G., 2004: 72; Patriotta G., 2003: 353). They point to the meanings that people have taken for granted.

A “narrative” is a *story* that tells a sequence of events significant to a narrator and his or her audiences. The story has a plot—the sequentiality—that comprises a beginning, a middle and an end, with its own logic that makes sense to the narrator (Wilkins A. L. and Thompson M. P., 1991: 20). It relates events in a temporal, and causal sequence (Denzin N. K., 1989: 37-8). The narratives also relate a self of the teller to a significant set of personal experience. They also create and interpret a structure of experience of the problematic occurrences as the narrator frames his experience in the narratives (Denzin N. K., 1989: 37-8). Actions are expressed as stories without which we cannot make sense of the social experience (Wilkins A. L. and Thompson M. P., 1991: 20).

Stories or narratives are contextually embedded; it is through the storytelling of a performance event that their meaning unfolds. They act as “repositories of accumulated wisdom.” The storytelling preserves knowledge (Brown J. S. and Duguid P., 1991: 45-6). Our personal experience—the personal knowledge—merges with what we hear and see as we listen to stories. This is “an embedded and fragmented process” in which we use our imaginations to “fill in the blanks and gaps between the lines with our own experience” (Boje M., 1991a: 107, 110). They have power in fostering belief, recall and commitments. Stories full of vivid details and organisational significance “allow us to experience events vicariously and therefore to believe and remember what we hear” (Wilkins A. L. and Thompson M. P., 1991: 20). Stories can be justifiably

interpreted in as much as the researcher understands it in situ (Boje M., 1991a: 190-10). They are material traces of learning and collective remembering process, social imprints of a meaningful course of events, documents, and records of human action (Patriotta G., 2003: 354). Stories also refer to an “exchange between two or more persons during which a past or anticipated experience was being referenced, recounted, interpreted or challenged. The meaning of the story is in the unique circumstances of each particular performance” (Boje M., 1991b: 8).

People “process information and manage collective memory of the organisation through storytelling” (Boje M., 1991b: 9). The narratives grant researcher an insight into how organisational actors represent and make sense of the problematic situations, by piecing together of evidence and clues of a reconstruction of experience. “A principle way we get a sense of what occurs and how things “really work” in organisations is through the stories we hear from others” (Wilkins A. L. and Thompson M. P., 1991: 20). Stories pass on central ideas of an organisation and common practices by giving concrete examples of ideas or by illustration of way things are done (Wilkins A. L. and Thompson M. P., 1991: 21). Organisation members become more aware of “the constructed nature of the narratives that guide their actions” as the narration helps them become more reflexive and multiple in perspectives (Wilkins A. L. and Thompson M. P., 1991: 22).

Creating and exchanging stories helps diagnosing state of trouble, keeping track of sequences of behaviour and theories, and working towards coherent understanding of the situation by imposing coherence on random sequence of events (Brown J. S. and Duguid P., 1991: 45). They “reflect the complex social

web within which work takes place and the relationship of the narrative, narrator, and audience to the specific events of practice” (Brown J. S. and Duguid P., 1991: 44-5). Insight accumulated from the shared narratives is socially constructed and distributed (Brown J. S. and Duguid P., 1991: 46). In making decision, people face a process of confirming new data and new interpretations as part of an unfolding story line. The old stories are recounted and compared to unfolding story lines to prevent repeating past mistakes and increase the likelihood of success (Boje M., 1991a: 106).

People tell stories to “make sense of an equivocal situation.” “Although ... each [individual] retains a part of the story line, a bit of interpretation, story performance practices, and some facts that confirm a line of reasoning, its and pieces of organisation experience are recounted socially to formulate recognisable, cogent, defensible, and seemingly rational collective accounts that will serve as precedent for individual assumption, decision, and action” (Boje M., 1991a: 106). In other words, “[s]tories are created, old stories are remembered, some are revised, and stories about the future are performed in the collective dialogue among organisational stakeholders” (Boje M., 1991b: 9). “They function ... as a usefully unconstrained means to interpret each new situation in the light of accumulated wisdom and constantly changing circumstances” (Brown J. S. and Duguid P., 1991: 44-5).

The above explains meaning of narratives as stories. They form a mean by which meaning of experience is expressed. At problematic situations, tacit knowledge is articulated. This opportunity provides researcher with the opportunity to use qualitative interview and observation techniques to collect the narratives, which normally remain tacit at routine circumstances.

### **The critical incident technique**

The CIT is a classification method that helps a researcher focus on themes and issues identified by respondents. It is suitable for generating knowledge and understanding based on thorough understanding of respondents' description of real-world phenomenon. The CIT focuses on events, incidents, and process of the problematic situation the way they are managed, and their perceived outcomes (Chell E., 1998, 2004: 45). A critical incident interview provides the researcher with retrospective account of experience. By being critical means that the respondents have good recall and the focus to probe, making the interview rich in context (Chell E., 1998, 2004: 45).

An incident is defined as observable human activity complete enough in itself to permit inferences and predictions to be made about a performer. The CIs refer to events and behaviours that have been described or observed to lead to success or failure in accomplishing a specific task—ones that contribute or detracts from a general aim of an activity, a smooth functioning of everyday practice, in a significant way (Bitner et al., 1990: 73). They interrupt ongoing routine sense-making activity, where cognitive dimensions of organisational knowledge is articulated (Patriotta G., 2004: 68). Certain features of the experience become figural or standout in the life-world whilst the other recede into background (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 136). The CIs are remembered problematic situations that have been reconstructed and interpreted that are not limited to an individual but extend to a group and interactional phenomenon. They are given multiple meanings by different persons, whose meaning may change over time (Denzin N. K., 1989: 40). Moreover, the CIT could yield accurate and consistent interpretations of the

respondents by allowing focus on specific issues and situations, narrowing down the incidents to what the respondent considers as important (Bitner et al., 1990: 73). Covering incidents in considerable detail enhances the completeness of data. It allows the respondents to reveal details of their experience from their own value, rather than the researchers' (Chell E. and Pittaway L., 1998: 26).

Focusing on the CIs helps the researcher to identify tacit knowledge. Tacit knowledge, deeply internalised or institutionalised, is mobilised in an almost automatic and irreflexive way. Non-routine activities, “breakdown or disruptions” refer to discontinuities in action that provides a possibility to “disentangle knowledge from consolidated work practices and routines.” Tacit know-how is clearly expressed as “present-at-hand” as it is applied in a deliberate way. The ongoing flow of action and sense-making is articulated as narratives, moves, and decisions. It points to specific learning or knowledge requirements and reveals stocks of knowledge not embodied in organisational artefacts. Analysis of the critical non-routine activity “opens up the possibility of deconstructing the meanings embodied in organisational artefacts, routines, and other knowledge-based activities” (Patriotta G., 2004: 65-7). People explicitly interact with the tacit background against which the knowledge is used. This process reveals knowledge references to the context visible to the researcher (Patriotta G., 2004: 68). The researcher looks for disruptive events conceived as turning points in an ongoing flow of activities in order to study how organisations create, use and disseminate knowledge (Patriotta G., 2004: 68).

The researcher starts by securing multiple cases and personal stories that embody phenomenon in question. This follows by locating the critical incidents of the subjects within a set of personal story the problematic experience to be

studied to discover content of the identified experience (Denzin N. K., 1989: 49). Interview questions ask the respondents to list and describe phase of work, which, from their recent experience, is a challenge in accomplishing tasks. It is vital to probe with follow-up questions to ensure that the respondents have given both comprehensive and detailed account (Edvardsson B., 1992: 18-21). The interviewer may ask: “Can you think of anything (else) ...?”, “How did it happen?”, “How did you feel and why?”, or “And then?” (Snell R., 1992: 13).

Ensuring sufficient depth of a critical incident poses some challenges. Reconstruction of past events may not fully reflect the experience, as the respondents’ thoughts, feelings, and perception could have been modified or reinterpreted in light of certain future event (Cope J. and Watts G., 2000: 116; Johnston R., 1995: 59). To assure a fair and thorough consideration requires triangulation of data to extend generalisability of finding. By checking documentary sources, or interviewing other respondents, the researcher is in a better position to identify commonalities of themes and visibility of recurring patterns (Bitner et al., 1990: 73; Chell E., 1998, 2004: 45). Since the researcher typically obtains a lot of complex and dramatic CIs, it is important that the interviewer becomes fully conversant with the interviewee to avoid risks of trivialising their diverse experiences (Edvardsson B., 1992: 18-21; Cope J. and Watts G., 2000: 112).

The critical incident interview helps the researcher focus on problematic phase of the phenomenon. The critical incident refers to non-routine events and behaviours critical to success or failure of work task, which disrupt a routine ongoing activity. Tacit knowledge is articulated as people make-sense of the situation and apply what has been taken for granted in a deliberate way as

narratives, moves and decisions. Once identified, the research applied in-depth data collection method to interpret meaning embedded in those expression.

### **In-depth techniques**

An in-depth data collection aims at understanding meaning from individual's lived experience at a critical incident. This phase applies qualitative interviews and observation techniques. The importance of narratives cannot be over-emphasised as a mean to convey the meaning embedded in experience. A researcher asks for respondents' stories of their experience and records the narratives in work process. His field note also records details of the phenomenon and reflections on methods and findings.

### **Qualitative interviews**

Generating a thick description from interviewing involves collecting a larger number of testimonies that provides variety of detail of a phenomenon (Yow V. R., 1994: 7). Multiple in-depth personal stories of an incident from different individuals are collected (Denzin N. K., 1989: 39). They permit a researcher to compare and contrast the stories of different subjects at different phase of experience of a phenomenon in order to identify convergence (Denzin N. K., 1989: 54-5). It is a parallel inquiry that helps clarify observations (Prasad P., 1993: 1407-8).

An interview gives a researcher the best access to participants' interpretation on past and current actions and events. "[It] is a powerful tool for attaining an in-depth meaning of another person's experience" (Yow V. R., 1994: 10). He can "learn about a way of life by studying the people who live it and asking them how they think about their experience" (Yow V. R., 1994: 7).

Moreover, the interview allows questioning of witnesses to take advantage of interaction in verbal evidence. The researcher is not left alone with documentary evidence to reflect and interpret a source of facts and contents because the interview reveals several facts behind ordinary lives of individuals and community. It renders more understandable, for example, underlying reasons for a decision, meaning of documents or artefacts, images and symbols people use to make sense of experience. It reveals various dimensions of life within a community or psychological reality—daily life at work, habitual thinking, informal rules on personal relationships at work (Yow V. R., 1994: 10). Further, factually untrue statements obtained from the interview may be psychologically true, which reveals imagination, symbolism or desire underlying such divergence (Yow V. R., 1994: 22-3).

Interviewing refers to a method of having “the first-person description of some specified domain of experience” by inspiring narrators to engage in acts of remembering, jogging memory and records, and presenting their world (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 138; Yow V. R., 1994: 2). Doing so requires a course of dialogue to be largely set by the respondents, with an exception of opening question, in which their own terms lead to follow-up questions. The interview format begins with “short descriptive questions ... [that opens] for the respondents’ lengthier and detailed description” (Thompson C. J. *et al.*, 1989: 139). “The dialogue tends to be circular rather than linear; the descriptive questions employed by the interviewer flow from the course of the dialogue, not from a pre-determined path.” The interviewer is a “non-directive listener,” who provides a context that the respondents freely describe their experience in detail (Thompson C. J., Locander W. B. and Pollio H. R., 1989:

138). In order to see the world from their experience, the relationship between the interviewer and the interviewee must be an equal one; i.e., of “subject to subject,” not “subject to object” (Yow V. R., 1994: 2).

Encouraging the interviewee to tell stories is an appropriate way to study tacit skills because people frame their experience in the narratives (Wilkins A. L. and Thompson M. P., 1991: 20). Some tacit skills may be uncovered as the respondents express what is done in an organisation (Ambrosini and Bowman, 2001: 820). Focusing on specific events enables them to “bring about descriptions of experience,” by providing a full detailed description of the lived experience (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 138). This allows the researcher to gain an “experientially based understanding” pertaining to particular incidents (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 138-9). The researcher discover the interviewees’ tacit knowledge and skill by focusing on narrated accounts of their action in terms of what they do, how they do it and in what context. Asking for the action stories involves asking: “Can you describe a time when ...?” Further probing for further involves asking: “How does that happen?”, “what causes that?”, “Who is involved?”, “What influences that?” Questions such as “What did you think?” or “What did you know?” helps identifying past integrations or partial solutions – beliefs, imagination and an articulate form of knowledge – as subsidiary cues the respondents’ dwell in as they engage in actions. Asking “What was X like?” or “How did you feel when ...?” allow the respondents to describe what they understand based on their own experience, and allow the research to identify intuition and hunches. Questions related to the respondents’ use of formal guidance in their tasks, such as instruction manuals, allows the researcher to identify the extent formal rules of

action is mobilised.

The researcher then encourages them to think of examples of how they have performed in those experience stories, telling stories about their key experiential units. Questions include: “Could you tell us an example about ...?”, and “Could you narrate a story about the occurrence of ...?” (Ambrosini and Bowman, 2001: 822-3). The stories should be explained as their actions or active involvement (Ambrosini and Bowman, 2001: 822). Relying on their own terms also prevents the researcher from conceptual predilections (Thompson C. J., Locander W. B. and Pollio H. R., 1989: 138). The interviewer follows-up by asking the respondents for their actual account of experience and meanings that give substance to glossed statements—a superficial, partial, and sparse account of complex meaningful events. Follow-up questions include: “What is outside the frame of the story?”, “What is highlighted in the story?” and “What aspects are ignored or downplayed during the time frame of the story?” (Wilkins A. L. and Thompson M. P., 1991: 22).

The qualitative interviews asks the respondents to tell stories of their own experience. The first-person experience facing the problematic situation uncover knowledge that normally remains tacit. The researcher gains further details by asking for examples of how the interviewees performed in the experience by describing their action.

### **Observation**

Capturing tacit knowledge involves taking field notes of an observed phenomenon and researcher’s personal reflection. Geertz suggests the researcher make sense of “the initially enigmatical actions they observe when studying

foreign cultures in making sense of the observations” (Geertz C., 1973: 5). He should structure his observation by using conceptual resources from theories, specific concepts and secondary research (Barzelay M., 1993: 312).

To observe is to constantly search for “points of references, signposts, and regularities” that allow an observer to make sense of surroundings (Patriotta G., 2004: 58). The observed sequences are occasions for telling of stories. The interactional episodes illuminate unique features of the subject’s life and reveals commonalities shared with others (Denzin N. K., 1989: 21). To take the subject’s perspective on issues requires careful recording through field notes of the situation for recurring structural, interactional, and meaning patterns (Denzin N. K., 1989: 40-2). Since tacit skills are picked up by “osmosis”: they develop overtime, and are acquired through experience, the observation allows one to learn about context (Spender J. C., 1996: 68). For one of the most effective way to learn tacit skills is through personal contact and discussion, the researcher seeks to become “a knowledgeable member” of the group, by being “a regular in the situations where group members of the group routinely interact” (Pavitt K., 1991: 46; Ambrosini and Bowman, 2001: 824; Denzin N. K., 1989: 80).

Recording experiences from observation involves field-note taking. A researcher records detailed portrait of the situations (Burgess R. G., (2000: 166-74). The notes consist of personal reflection on the methods in dealing with problems, impressions, feelings, and hunches. They may reflect on process and procedures of the fieldwork, the way in which methods can be adopted, adapted and developed in particular settings. They may also cover preliminary analysis that provides framework for subsequent inquiries (Burgess R. G., 2000: 166-74). The researcher takes mental and briefly-jotted notes whenever it is impossible to

take full field-notes (Bryman A. and Bell E., 2003: 331-3).

### **Analysing**

Collected data is processed into codes and categories to produce meaningful interpretations of sequence of actions as an analytical process. The researcher interprets by doing “everything within his power to make himself informed ... by making [his] mind the repository of the (potential) responses a given text might call out” (Fish S. E., 1980: 48-9). By analysing, he understands how individuals articulate tacit knowledge by “weaving webs of signification” (Geertz C., 1973; Patriotta G., 2004: 78).

The analysis dissects units of experience into relevant and meaningful order of statements, sequences and actions (Denzin N. K., 1989: 120). To understand subjects’ experience from their point of view, the researcher unfolds meanings embedded in their experience both from narratives and field-notes. Collecting multiple stories allows the researcher to compare and contrast these stories from different phases of experience to identify convergence (Denzin N. K., 1989: 54-5). The researcher dissects the phenomenon to uncover, define and analyse essential structures, recurring forms of conduct, experience, and meaning (Denzin N. K., 1989: 55). Text is displayed and subdivided into key action units to reveal recurring features of key terms and phrases (Denzin N. K., 1989: 44-6). In this research, the units of experience and actions are dissected in order to identify subsidiary clues, and modes – or types – of integration, and to be coded and categorised in steps that follow.

To read the “meaning of words and signs within narrative and interactional texts,” the researcher directs attention to the key terms in narratives. “[T]hese

terms (signs) are organised by a code, or a system of larger meanings (Denzin N. K., 1989: 57; Tsouskas H., 1991: 571, 581)<sup>4</sup> The process is operationalised by coding, categorising and classifying. Coding is a process of reading through sets of transcripts, field-notes, or documents, reviewing codes, considering more general theoretical ideas in relation to codes and data. As a unitising process, “raw data are systemically transformed and aggregated into units which permit precise description of relevant content characteristics ... [that] involves defining units, separating them along their boundaries, and identifying them for subsequent analysis” (Lincoln Y. S. and Guba E. G., 1985: 203).<sup>5</sup> Here, the coding identifies subjects’ key action units performing under each discrete event: they “are tags or labels for assigning units of meaning to ... information compiled during a study” (Miles M. B. and Huberman A. M., 1994: 56; Lofland and Lofland, 1995: 187). By providing a link between the data collection and conceptual rendering, the coding becomes fundamental means of developing analysis (Charmaz K., 1983: 111-2; Lofland and Lofland, 1995: 186).

In categorising or classifying, the unitised codes are organised into categories that provide “descriptive or inferential information about context or setting.” It involves “sorting units into provisional categories on the basis of “look-alike” characteristics, which may ... initially be only tacitly understood” (Lincoln Y. S. and Guba E. G., 1985: 203). To categorise is a process of repeated, careful readings and sorting of the incidents into groups and categories according to similarities in the reported experiences that precede articulating or identifying exact nature of similarity. The data is sorted, combined and resorted following these categories (Bitner et al., 1990: 74). On the one hand, the incidents are classified based on impacts, people involved and what respondents

perceive to be critical. On the other, the action units are organised into different skill categories.

However, coding data into discrete units could result in a loss of context and narrative flow (Bryman A. and Bell E., 2003: 434). Keeping coding and data in perspective is achieved by constant comparison, a process of maintaining a close connection between data and conceptualisation, a correspondence between concepts, categories and their indicators, or between phenomena being coded and categorised (Charmaz K., 2000: 515; Bryman A. and Bell E., 2003: 435-7). To actively coding and categorising, or classifying, preserve images of experience, since both processes sharpen the researcher's ability to ask questions about the data (Charmaz K., 2000: 525-6). The classification involves viewing each interview transcript as a whole and relates separate passages of the transcript to its overall content. These are then related to each other and "patterns of commonalities" are identified. This process improves interpretive vision as the researcher seeks to describe common patterns in experiences, by "continuously referring back to individual transcripts to ensure that the patterns of commonalities are not rendered in abstract terms removed from respondent experience" (Thompson C. J *et al.*, 1989: 142). Further, memoing is an aid to the generation of concepts and categories that helps keeping the code active. It consists of notes the researcher write to himself on elements as coding or concepts as reminders about what the terms mean as points of reflections. It helps the researcher crystallising ideas, and not losing track of thoughts (Bryman A. and Bell E., 2003: 432).

An analysis begins with having subject's experience broken down into action sequences, and with having events under which these action perform

identified. Meaning of experience emerges as the actions units are classified into different skill sets, and the critical incident is identified based on common characteristics and respondents' perception.

### **Reliability & validity**

Specific nature of this research contributes a rich insight to the case, though challenges are present in generalising its findings across different research context (Walsham G., 1995: 79).

As a methodological choice, this research employs a "sophisticated rigour," which refers to any research "employing multiple methods, seeking out diverse empirical situations and developing interpretations ... in the worlds of lived experience" (Denzin N. K., 1978: 167). Yet, reconstruction of past events may not fully reflect the experience, thoughts and feelings at present time, as the respondents' perception could have been modified or reinterpreted in light of some future event (Cope J. and Watts G., 2000: 116; Johnston R., 1995: 59). Covering critical incidents in considerable detail by triangulating data sources and multiple research methods supports the validity of findings.<sup>6</sup> It provides an opportunity for confirming that researcher's interpretation and understanding of the subject's experience is consistent with that of the subject and others who share similar experience. The research employs interview, observation and secondary research to obtain meaning of multiple subjects' lived experience of the critical incidents. He makes his interpretation "seeable by others" (Thompson C. J., *et al.*, 1989: 140). It helps identifying commonality in themes, and enhancing generalisability and repetition in patterns among experiences. The multiple sources of data, both primary and secondary, also confirm the

researcher's correct understanding of the phenomenon under investigation by allowing the cross-checking and making himself an informed reader. Further, weaving the "web of signification" as an interpretive process generates several references into any form of activity. It successfully addresses to the problem of rhetorical representation by the verisimilitude of thick description, ensuring that any description produced are sound, adequate, and able to be confirmed and sustained (Patriotta G., 2004: 76; Denzin N. K., 1989: 83).

As a result, the interpretive method affords its own justification (Thompson C. J. *et al.*, 1989: 143). Verification as an internal process that capitalises on the tacit knowledge, insight and intuition of the researcher is based on his seeing "things-in-the-world." His understanding of the case allows them to see meaningful pattern in the subjects' experience. Interpretation based on researcher's understanding is based in-the-world, as its correctness is verified by the experienced insight.

### **Research Site**

The fieldwork was conducted at two papermills: Curtis Fine Papers, and Tullis Russell Papermakers, during 4-10.2007 and 3-5.2009. Different teams of production workers were interviewed. At each mill, the production workers work with specific machinery, team and shift, for which they have experience working together for an extended amount of time, ranging from 1-16 years, according to interviewees. The key workers of each team are the machineman, beaterman, drierman, and machine assistant. The beaterman and machineman are among the most experienced in each team for they perform the most comprehensive roles covering respectively stock preparation and papermachine

areas. Their roles involves working at the computer control interface, which is usually the starting point of their interaction with the actual production process. In some cases, the researcher interviewed production managers about their responsibility for production at the mill level, and software engineers who look after the control system. The early phase of the fieldwork involves with interviewing production workers of various teams/shifts, across different paper machines, whilst the later phase involves spending extended period of time with single production team/shift at the same machine.

As a piece of interpretive research, this study applies in-depth interview and observation techniques to take the subject's perspective of phenomenon in question, by the researcher developing his tacit knowledge of meaning embedded in text or slices of human action. The inquiry focuses on critical incidents at breakdowns of the work routines. At the critical incidents, the researcher could study the tacit knowledge, as reflected by the subjects. Early in the fieldwork, the interview questions asked the respondents for overview of the papermaking process, their roles and involvement. In the later stage, the researcher asked probing questions based on the incident: how respondents perform the task, whom they interact with, what the process involves, the way they work with control system and, any challenging issues. Greater emphasis has been placed alongside the in-depth interview, however. The granted level of access based on the health & safety regulation allowed live observation to be conducted entirely alongside the interview taken place in the control room.

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<sup>1</sup> See, for example, Sandberg J. (2000: 9-25); Dreyfus H. L. & Dreyfus S. E. (1986); Schön D. A. (1983); Benner P. E. (1984); Atkinson P. (1988: 441-65); Barley S. R. (1996: 404-41); Brown J. S. & Duguid P. (1991: 40-57); Garfinkel

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H. (1986); Kusterer K. C. (1978); Livingston E. (1987); and Tyre M. J. & Von Hippel E. (1997: 71-83).

<sup>2</sup> Although a quantitative method may also be used, the qualitative method is more suitable.

<sup>3</sup> Denzin N. K. (1989: 30-1)

<sup>4</sup> In addition, the narrative texts may include terms that signify differently from their surface meanings, such as metaphor, metonymy, similes, or analogy, which, in some cases, are better able at expressing the continuous flow of experience than literal terms.

<sup>5</sup> Moreover, the data may be coded in more than one way. See Bryman A. and Bell E. (2003: 435-7) for further detail.

<sup>6</sup> More generally, the triangulation refers to a use of more than one method of inquiry or source of data, multiple observers or theoretical perspectives. See Bryman A. and Bell E. (2003: 291) and Denzin, N. K. (1970: 310)

## **Conclusion**

This chapter has presented the methodological choice for the current study of tacit knowledge. The first section highlights the importance of researcher's own understanding into the subject's experience, by the use of his own human instrument. In the thick description, the verisimilitude of the critical incidents helps the researcher describe what and how the tacit knowledge embedded in the context is articulated and exercised. Treating data as experiential units helps discovering what the tacit knowledge of the person in performing tasks. The last section addresses the issues of validity. The verisimilitude of the thick description, the multiple techniques, sources of data, and respondents confirms the validity of research.

## **Chapter 4: Impact of computer technology in paper production process**

### **Introduction**

The use of computer in the paper production process as a continuous process industry involves the automation, or substitution, of tasks performed by men. This chapter examines what impact on knowledge and skills the computerised production process entails. This chapter is divided into four sections. The first explores nature of work in the paper production process. The second section considers computer impact on work process and skills in general and paper production contexts. The third section describes development of computerised control and monitoring systems and nature of work from their first application in the 1960s. Modern control systems automates control and monitoring tasks in paper making and serve as decision-support tools to the operators in dealing with process-related problems. The fourth section identifies knowledge and skills required in working with the computer-mediated work process.

The term ‘computer technology’ (CT) shall be used to denote the microprocessor-based technology that performs information processing. The term ‘system’ also refers to similar meaning. ‘Computerisation’ refers to the use of computer in the work process. Its major application is to automate, or substitute for, tasks normally performed by men (both physical and mental knowledge; however, they share the same tacit root and structure). Possibilities include process control and monitoring tasks in the continuous manufacturing or, for example, handling of data transaction in white-collar service contexts. Further, related terms as skill and knowledge are often used interchangeably.

This is because, according to the basis of tacit knowledge considered in the earlier chapter, they share similar meaning. They are based on the notion of tacit knowledge.

### **1 – Work in the paper production process**

Modern paper production seeks to improve economic performance of increasing productivity and lowering unit production costs. The gain is achieved mainly through process innovations. These are technological change that centres on use of computerised process control and monitoring systems, and reorganisation of labour practices to foster teamwork, individual employee involvement and flexibility. Technological innovation in process machinery have focused on raising output through higher speeds, in addition to creating wider machinery through major investment into new machinery or rebuilding, modernising, existing machines. Maximising operating capacity and increasing paper machine output are achieved by increasing machine speed to reduce production costs per unit (Vallas S. P., 2001: 13; Holmes J., 1997: 21-2).<sup>1</sup> Moreover, demand for most kinds of mill labour is quite inelastic: i.e., demand for labour does not vary as much as changing demand for products. The process is a continuous process and adjustments to fluctuating product demand are met by varying machine speed, rather than reducing the number of workers in the mill (Holmes J., 1997: 20).

Paper and board machines are large continuous-process machines and paper chemistry is very complex. The machine operator must be flexible in problem-solving behaviour, using all sorts of knowledge. Their diagnostic performance increases with experience (Leppänen A., 2001: 579). Paper

manufacturer requires a highly skilled, experienced, full-time labour force that can operate advanced machinery continuously (Holmes J., 1997: 21). A modern papermaking machine is enormous, and most mills have at most two or three machines (Holmes J., 1997: 13-4).<sup>2</sup> It is also vital to avoid machine breakdowns.

Like other capital-intensive industries, the paper industry contains two main sorts of manual jobs: production workers (operators) and maintenance workers. The maintenance workers are responsible for the upkeep of the plant and equipment, electricians, pipe fitters, millwrights, welders, carpenters and so forth, in order to maintain the machine and the process-monitoring system (Smith M. R., 1999: 694).<sup>3</sup> Machine maintenance skills are acquired through lengthy training, through apprenticeships in skilled trades such as electrician, pipefitter, or millwright. The acquired skills enable the worker to maintain all kinds of machinery, and hence are portable and transferable. They can also be recruited into the paper industry from other sectors (Holmes J., 1997: 14).

Production workers run paper machines, pulping, bleaching, and power control process; whose function, in other words, is required to keep the pulp flowing and sheet running. Production skills are embodied in several key occupations; the senior pulp operator (traditionally called the beater engineer or beaterman) in the pulp room, and, on the paper machine, the positions of machine tender and back tender. The senior pulp operator is responsible for the preparation of the pulp 'furnish' to be fed to the paper machines. The machine tender and back tender control the paper-making machine and now act on information supplied by the sophisticated computerised process-monitoring system to adjust the thickness, wetness, or tensility of the sheet within the various stages of the machine itself. Pulp operators and machine tenders do not

serve formal craft apprenticeships; their route into skilled work involves the gradual ascent of internal career ladders, and their skills are acquired from 'experience'. Machine operators often work for long periods in lesser-skilled positions, working their way up the line of progression on the paper machine, watching actions of more skilled machinemen (progressively the winderman, the back tender, and the machine tender). Over time, they acquire the detailed knowledge and experience required to control the papermaking machine. These acquired skills are industry specific and sometimes, given the temperamental nature of paper machines, mill or even machine specific (Holmes J., 1997: 14). Even so, there is significant variation in education and experience, and in environment and organisation support for individual learning. Educational background typically ranges from no vocational training to around three years (Leppänen A., 2001: 581).

There are different degrees of technological inclination, for example, between the US and the UK paper-makers. In the US, a greater scale of the industry, a relatively higher degree of production intensity and product standardisation, and a relatively more open attitude towards investment and innovation provide the manufacturers with greater incentive to stay current with the most up-to-date machinery (Magee G. B., 2009: 42). This explains the higher degree of formal training to the US workforce, and a relative eminence of craft practice in the UK paper-makers.

The subject of paper production is broader than one crew. Paper-making involves not one single worker but a group of workers or a crew working on a paper machine. The crews must have an effective mean of information transmission and a joint understanding of paper-making concepts (Leppänen A.,

2001: 579-80). Work requires that all workers of one paper machine observe the process both through the Visual Display Units (VDUs) of the automatic operation system and beside the paper machine itself, make hypotheses about state of the process and actions required, and communicate their observations, decisions or past actions to other group members. The paper-making is a rapid process; yet, delays are typical. It can take a number of hours for an impact of change made in one area to become visible in the subsequent process, as adjustment in mass concentration at the head box at wet end only becomes evident as changing parameters of paper quality at dry end.

In such a complex process involving not only one person, but a group of people, co-operation and communication requires accurate, and mutually accepted understanding to be able to exchange information in the critical phrases of work process (e.g., during production disturbances). Accurate concepts and sufficient knowledge of the work process are also prerequisites for learning from the process events and for sharing experiences and knowledge in the work community to improve the work process further (Leppänen A., 2001: 581).

Flexibility and interchangeability are essential in modern paper production. They require workers to be multi-skilled. Craft employees take on a broader range of tasks (e.g., one or another less demanding skill–standard welding, oiling–may be assigned to the more demanding crafts; such as, pipe fitter, and millwright). Multi-crafting involves elaborate programmes in which craft employees are trained in a range of skills (Smith M. R., 1999: 695). In the reorganisation of the maintenance work undertaken by the skilled trades, given the high maintenance costs associated with the capital-intensive nature of continuous production, bargaining has focused on reducing number of job

classifications, jurisdictional restrictions, and number of workers in maintenance. Programmes designed to encourage skilled tradesworkers to become multi-crafted or multi-skilled further accentuate this trend (Holmes J., 1997: 21). The definition of production jobs has also been broadened by, for example, asking machine operators to do some of the paper testing, to absorb the work of the stock preparation person, or to help with non-routine maintenance and repair work (Holmes J., 1997: 21). Workers are required to perform mutual assistance, meaning the craft employees are required to assist each other in completing tasks. Operators are also required to perform minor maintenance in some mills. Pay and progression has been tied to skills acquisition, work rotation and teamwork (Smith M. R., 1999: 695).

## **2 – Impact of computer as an automation technology on work and skills**

An automated technology changes a nature of work. It substitutes human's tasks with automatic operations. These can be physical, mental or both (Parasuraman R. and Riley V., 1997: 230-54). A general idea is that as the relatively simpler tasks are automated, and as the newer technologies are increasingly capable of performing more sophisticated functions, a human is responsible for work content that lies beyond the technology's capability. The work becomes more mental; his role involves monitoring an automated work process and intervening in a situation the technology cannot handle. In manufacturing, this often results in a machine operator performing as an intermittent machine feeder or loader, who monitors and controls process machinery and a whole manufacturing process. He becomes a proprietor of the system who makes decisions as he controls the process, rather than merely

executing tasks (Huys R. *et al.*, 1999: 67).

An early automated technology in manufacturing assumes a form of process mechanisation. In a chemical industry, for example, “practically all physical production and material-handling is done by the automated process regulated by automatic controls” (Nichols T. and Beynon H., 1977: xiii). This results in an elimination of traditional work skills (deskilling) and an emergence of new skills (reskilling) and new responsibilities. Yet, the evidence reveals different conclusion across different industries. The distinction is an extent of which the unique craft skills apply. In the craft industry, a high proportion of workers maintain their traditional skills; the work depends on “the special skills of journeymen workers ... [whose] essential feature is a lack of standardisation of the product.” Constantly changing nature of the product “inhibits the standardization, or “rationalization” of the work process” (Blauner R., 1964: 35-6).

Early evidence of the automation suggests a separation of the theoretical and practical skills, where the former assume a more prominent role and the latter becomes “debased.” The traditional activities are superseded by monitoring the automatic processes that involves making sense of observed dials and gauges of key parameters, such as temperature, pressure and flows, and logging these readings (Nichols T. and Beynon H., 1977: 24). They improvise an adjustment to the process by moving a lever or a knob, then observing and listening to responses (Nichols T. and Beynon H., 1977: 19). These *new* activities are the tacit skills that “cannot be taught.” It take years to “get to know” knowledge specific to plants and equipments (Nichols T. and Beynon H., 1977: 23).

The automation creates a physical as well as a psychic distance between the operators and the process, as they work from the control room. They work mainly with symbolic representations or “abstraction” and directly engage the machines only when they are down (Zuboff S., 1988: 58-96; Vallas S. P. and Beck J. P., 1996: 346-7).

Operators’ distance from the actual process places even greater reliance on the human operators in order to realise full potential of the technology in ensuring stable operation and the best product quality (Fischer M. and Röben P., 2002: 25-9; Burriss B. H., 1998: 141-57; Vallas S. P., 2001: 17; Holmes J., 1997: 11). The automation in continuous process industries also leads to the process that is stochastic and continuous in nature. The technology alters operators’ roles in industries such as paper, chemicals, autos, and machine tools production towards “system regulator” who steers machines as they operate autonomously and continuously (Huys R., *et al.*, 1999: 67-9). The stochastic process consists of routine operations punctuated with periods of non-routine variances accompanying high attentiveness and activity (Gerwin D. and Kolodny H., 1992: 188-9). Stochastic events cannot be predicted or planned for in advance (Gerwin D. and Kolodny H., 1992: 188-9). The stochastic incidents; e.g., break downs or product faults, are unpredictable and random, which cannot be handled, or automated, by the system. The stochastic and continuous process is “integrative by nature and demands corresponding levels of integration and co-ordination from the social and support systems” (Gerwin D. and Kolodny H., 1992: 187). Although the automation eases the workers’ physical burden, it takes high levels of attentiveness to deal with this high variability in workload consisting of long period of relative inactivity and occasional periods of extremely arduous activity

(Huys R. *et al.*, 1999: 67-93; Blauner R., 1968).

A computer is another form of the automation technology. The term “computer” refers to a microprocessor-based technology that performs information processing. It substitutes for human’s mental task in a sense-making activity. The computer-controlled process machinery and sensory equipments make possible the substitution of physical-sensory tasks and convert physical-sensory data into computer-generated information. These are, for example, process control and monitoring systems in manufacturing or data handling systems in white-collar service industries.

The computer raises threshold of skills required in performing work (Burriss B. H., 1998: 141). It eliminates low-level jobs and shifts employment towards the more highly skilled and often technical occupations (Barley. S. R., 1996: 404). For example, the use of sales-supporting system at the bank’s customer service representative (CSR) to aid judgement by guiding interaction with customers results in higher skills required and higher pay. The IT system installed, intertwined with customer interaction, “requires higher levels of education, experience and cognitive ability to be used effectively especially when the financial product set ... is complex and varied.” It is also difficult to script unpredictable customer interactions into the sales-supporting technology (Hunter L. W. and Lafkas. J. J., 2003: 239). Interacting with customers using the sales-supporting system requires two layers of skill. First, the CSR needs to acquire the traditional customer service experience to deliver good service, as well as the technical knowledge of product and services that match customer needs. Second, they needs skills to follow the guideline provided by the system, whilst being able to personally service the customers.

The nature of work becomes more complex as computer eliminates simpler errors. Only the more complex part of work remains for the workers. For example, for bank accountants the computer automates routine manual and repetitive processes in data transfer, data entry and several computations (Murnane, R. J., and Levy, F., 1996). It frees humans to spend more time on more difficult aspects of their job that involve problem-solving, analysing, and communicating with other staffs. It allows the accountants more time on performing analysis and higher-level problem-solving (i.e., data rework, valuation and analysis), which forms the more difficult part of their job. Yet, it did not eliminate the need for knowledge underlying routine work. The computer cannot handle the process involved in building a base of analogies, or reasoning by analogy, that takes place in data rework, valuation and analysing jobs. Nor can it conduct searches or communicate, and negotiate, with other persons (Murnane, R. J. and Levy, F. (1996).

Confusion arises for impacts on skills as a result of the computerisation. A “skill bifurcation” refers to a co-existence of “occupational upgrading and deskilling” caused by the computerisation (Diprete T. A., 1988: 725-46). A general tendency is that the computer causes people to become responsible for more complex work instead of the routine one, as they move towards an upper functional hierarchy. Any occupational study that focuses on a performance of tasks in a static way often reports deskilling as an empirical finding. In the semiconductor industry, for example, the computerisation requires the additional mental skills needed to cope with the abstract work content, whilst lowering reliance on the operators’ physical involvement. Greater reliance is placed on their supervision and decisive intervention at a stochastic circumstance. The

process reliance on the *traditional* operators diminishes as technicians and engineers assume their role and responsibility in controlling the automated production process. The industry witnesses less dependency on the operators unique skills when their operators have been unable to catch up with the increasing skill requirement (Brown and Campbell, 2001: 450-65).

In paper-making, an application of the computerised control and monitoring technology is the automation—or substitution—of tasks performed by men. Technological development has produced modern control system that is capable of handling increasingly complex and less routine tasks. An introduction of the automated process control interposes symbolic, computer-mediated representations between machine tenders and the production process (Vallas S. P. and Beck J. P., 1996: 346). The increasingly sophisticated sensory equipments that replace manual methods of collecting process data alter the decision-making methods and procedures within the production area (Vallas S. P. and Beck J. P. (1996: 346). The integrated system opens possibilities of connecting various computer systems in the mill, thanks to the computer's capability to link and integrate with other mechanical, sensory or other microprocessor-based equipment performing diverse tasks (Halle D., 1984: 101-2).

Working with the computer technology calls for operators' handling of an abstract thought process. It combines an ability to work with abstract symbolism and an ability to perform explicit inferences and procedural reasoning (Zuboff S., 1988: 73).<sup>4</sup> Various forms of the abstract representation include numerical and visual cues, such as diagrams, graphs, or maps. In their interactions with work, options are considered and choices are made that is translated into the terms of the information system (Zuboff S., 1988: 71). The operators interact with the

process through computer interfaces, using keyboards and touch screen monitors, to monitor and adjust various details of the process, key parameters, and changes, such as acidity, fibre length, pulp, brightness, thickness, weight and tensile strength.

### **3 – Development of computerisation in paper production**

The development of computerised automation in manufacturing begins with the early programmable numerically control systems from the late 1960s, in the production of machine tools. This allows for standardised production of larger product varieties at lower set-up costs and costs of switching among different productions. In paper industry, computer helps ensuring consistent operations by continuously regulating process variables in routine situations. Its earliest form is the conventional control loop, which is later developed into sequential control and multivariable control. The conventional control system takes the form of control loop feedback, or, in other words, the proportional–integral–derivative controller (PID controller). Major discrete control units both take the form of the proportional-integral derivative (PID) controller. Numerous contemporary industrial settings employ the control unit in this form. An apparent benefit is the ability for controls to function in identical fashion, lowering the need for application-related expertise, or the system-related knowledge in fine-tuning and maintenance (Pulkkinen M. (2005: 62-3).

The conventional control system correlates production data to shorten action-feedback loop of controlled variables, by continuously analysing and comparing these variables to target values or setpoints stored in the memory, or set by the papermaker. Any significant change of controlled variables is

automatically logged and reported to the operators. The system alerts the operators when faults arise to avoid potential failures and expensive downtime. Any deviation can be dealt with by adjusting the operation variables to return them to its setpoint (Caie A. and Mulders P., 1980: 22).

The paper production process employs separate control loops, with one loop per parameter; each loop is modular in design (for example, moisture and weight loops) that can be turned on and off separately. Internal algorithm is inflexible and only allows for low tolerance of errors in contemporary standards. It relies on empirically driven decoupling coefficients to address process interactions with decoupling normally performed at two loops at a time, which does not account for process dynamics in the feed-forward control calculations. Control are often erratic when the parameters go out of range at non-routine situations, requiring full operators' manual involvement during critical phases of work, for example, in paper grade change, when the feedback control needs to be temporarily suspended (McQuillin D. and Huizinga P. W., 1994: 26). Early digital paper quality control system by Measurex and Accuray by early 70s requires a "baby-sitter" or a team on site in its operations (*International Paper World*, 2005a: 44-50).

The conventional control loop has developed into the sequential automatic PID control programming by the mid-80s to simplify the execution of routine papermaking tasks. This enhances capacity of the conventional control scheme by integrating separate conventional control loops. The operator activates control at workstation, and a recipe display, to automatically prepare for new formulas, at automatic and orderly machine start-up, shut-down, and grade changing (*Paper*, 1987a: 27). Their direct involvement is needed only in the case of

problems with process or equipment malfunction, notified by alarm. The sequential program stops with alarming, when the process does not match proper condition for proceeding to the next step in a series of actions. However, this could not replace the operator's involvement. Controlling the process requires work and knowledge based on actual operational experience. Familiar operators are better at running the process more effectively (Kaminaga H., 1994: 16).

Subsequent multivariable control technology allows the control system to simultaneously handle multiple control variables and their interactions by integrating several single-loop controllers that do not necessarily have one-to-one relationship. This control scheme provides better control of interacting process as it simultaneously manipulates multiple actuators to maintain multiple process variables at setpoints or within defined limits and autonomously calculate for new setpoints that adapt to current process conditions (McQuillin D. and Huizinga P. W., 1994: 26; *Paper Technology*, 1994b: 43). Major forms of multivariate control embrace fuzzy logic and artificial neural network algorithm.

The multivariate PID controllers have incorporated fuzzy logic into paper making since early 80s for further flexible and adaptive process control (Pulkkinen M., 2005: 62-3). Recent systems also significantly benefit from more powerful computing capacity (Pulkkinen M., 2005: 62-3). The fuzzy logic-based algorithms provide benefits where the control target is other than direct tuning of a setpoint value; i.e., the control target, when the process controlled is non-linear and must be controlled in various ways. This control logic allows accuracy and speed targets to vary within control range, and the capability to simultaneously fine-tune and react to major disturbances (Tarhonen P., 2005: 14). Moreover, control level of the fuzzy PI controller can be divided into several zones,

providing extra flexibility (Tarhonen P., 2005: 14). Likewise, an artificial neural network (ANN) approaches information processing method of biological nervous systems; i.e., brain. The ANN mobilises a large number of highly interconnected processing elements working in unison in solving problems. It learns by example, just like people, and is configurable for specific application through a learning process: the system can be trained using a range of input data with any disturbances or fundamental changes. Recent increase in computing power gives sufficient capacity for fast paper machine control (Pulkkinen M., 2005: 62-3). Like the fuzzy logic, the ANN control identifies sources of problems that may arise from multiple causes.

Computerised control equipment not only substitutes for operators' control of the process but also makes visible process data and provides a basis for integration of control and information systems across distinctive parts of the papermaking process. Interest in the system integration began in the early 1970s with attempts to merge "islands of computers" within papermills (*Paper*, 1980: 9). There is rapid diffusion of computer technologies during the period of late 1970s towards mid-80 taking the forms of, for example, computer-aided design, computer-aided manufacturing, robotics, artificial intelligence and flexible manufacturing systems. In manufacturing, the attempt reflects in the decentralised, but integrated, computerisation of production process.

Millwide networks for communication and control in early-1970s provided a set of communications, storage and analytic functions to employees across functional divisions, bringing appropriate information wherever and whenever needed, whilst supplementing process automation (Land D. and Kaunonen A., 2000: 47; Vallas S. P. and Beck J. P., 1996: 348-9).<sup>5</sup> This provided

comprehensive and transparent views of the operations to the workers and managers (Vallas S. P. and Beck J. P., 1996: 348-9). Early development allowed users to establish a common database covering an entire mill's operations. Production management were able to obtain current and comparative information on numerous aspects of the mills, to improve decision-making, efficiencies and control costs (*Paper*, 1980: 12).

Subsequent developments performed converted process data into production and business information, processing data as information clusters that incorporated repertoires of stored knowledge such as as real-time online production or quality reporting presented to the operators for direct feedback control (*Paper*, 1987: 17). Between mid and late 1980s, embedded computer-based intelligence laid the foundation for greater control flexibility in a standardised production process, by integrating real-time production data and control system (*Paper*, 1987b: 17). Integrated systems were able to perform tasks traditionally handled by separate discrete automation systems, leading to easier and more economic supervision of the process. Several control loops were monitored simultaneously and were programmed to maintain key variables at target, and alert operators to exceptional process conditions (*Paper*, 1987a: 27). The distributed control system (DCS) consists of decentralised control units integrated through communication network. The DCS provides the operators with a wealth of production data, as a tool to track the operations of automated processes. The millwide information systems (MIS) facilitated efficient management of production process and centralise information reporting from computers and control systems throughout the mill (Lidhamn I., 1994: 24). At the Howe Sound mill in Canada, for instance, the MIS integrated production and

quality information of all processes from the DCS all over the mill, including paper machine computer system, automated tracking system, pulp quality monitor and laboratory data. The MIS provides distributed operator stations providing same information throughout the production site (Kaminaga H., 1994: 16).

The 1990s development aimed towards more efficient integration of control and information system (*Paper Technology*, 1994a: 42). The elimination of external interfaces enabled faster data processing, and integration of controls for different processes on a single control platform (*World Paper*, 1995: 23; Lidhamn I., 1994: 24). Simultaneous processing of data enabled quicker identification of faults (McQuillin D. and Huizinga P. W., 1994: 26). It is also possible to integrate existing distributed control, with new control, a new scanning gauge system, real-time millwide process information and lab quality system into one control scheme (McQuillin D. and Huizinga P. W., 1994: 26). Discrete control units become more autonomous, being self-adaptive to process conditions, and integrable with the existing control equipments. Most machines start to have complete digital control system to handle control directly (*International Paper World*, 2005a: 44-50).

Since then, rapid increase in computing power and system openness in forms of commodified communication hardware and software allows for cooperation among applications on different hardware and software vintages (Land D. and Kaunonen A., 2000: 47). Powerful microprocessors combined with sophisticated control modelling enable control strategies for tighter co-ordination among production areas. Systems such as the Millennium System in 2000 mobilised open architecture for flexible expansion to integrate process control

and information systems in the mill that do not share common platform (*Paper Technology*, 2000b: 13). The ABB Industrial Systems function as central control unit by integrating different microprocessor-embedded devices to work as single control system. The system links various speed drives to the open control system where they are controlled by central process controllers. The operators control all drive functions from operating station or PC, controlling remotely such parameters as speed, torque, interlocking drives and reading drive status. They are also alerted by central reporting alarms (*Paper Technology*, 1997: 20).

### **Decision-support features of the modern computerised systems**

Such developments have created modern sophisticated control and monitoring systems that simultaneously take into account process parameters, their interactions and dynamics across various areas of the papermaking process, whose capability approaches the exercise of tacit knowledge by accounting for experience-based learning and problem-solving, and being adaptive to various process conditions.<sup>6</sup> They also support operator's problem-solving by providing an articulated trigger to their tacit knowledge as process visibility, diagnosis and troubleshooting information, and knowledge resources. At non-stochastic events, the system provides automated process control, whilst providing process visibility as system-generated abstract information. At the stochastic situations, however, the system alerts the operators typically by prompts or alarms, and provides a) symbolic representation of the process as numerical data and charts, b) interpretation as process diagnosis and troubleshoot, outcome prediction, interactive process simulation, and corrective advice, and c) prompting knowledge resources as consultative and reference materials defined by both mills and suppliers.

The control system provides process visibility through the traditional form of the distributed control system (DCS). The Statistical Process Control (SPC) installed at the Nashua Corporation in 1979, for instance, conducts statistical interpretation of fluctuations between random and systematic variations in the production parameters by probability theories (Berger R. W. and Hart T., 1986: 4). The operators see whether key process parameters deviate from the target values, set by engineers, and decisively intervene at statistical deviation (Vallas S. P. and Beck J. P., 1996: 347-8; Karlsson M. and Ståhl C. W., 2000: 25).

Process diagnosis and troubleshooting provides up-to-date information of a current process state, whilst identifying and tracing causes, and automatically correcting process problems. Most modern control systems possess this capability. For instance, the Energy Monitoring and Targeting software at Cladwells mill in 1997 highlights trends and estimates costs of energy use, detects unaccountable consumption increase, diagnoses causes of increase from various sources across different time periods, and performs automatic routine maintenance (Watson K., 1997: 29). The Valmet and Neles Automation system installed at the paper machine in 2000 provides detailed views of the production process to support the operator's identification of mechanical faults (e.g., faulty pumps). It displays interlock windows and key information relating to faults, such as loop description, operating procedures, common causes and solutions drawn from stored knowledge (Land D. and Kaunonen A., 2000: 47). The Conex fault inspection system and the Parsytec web inspection system in 2003 mobilises cameras and image processing softwares to assist the operators' detection and troubleshoot of faulty sheets and web breaks, based on its extensive library of different fault characteristics. The operators are able to

categorise different types of faults (e.g., watermarks, oil marks, edge and material faults) and the causes by consulting the documentation with respect to each fault type (*International Paper World*, 2003a: 14-6; *International Paper World*, 2003b: 38-40). At the wet end, the IQInsight in 2005 supports the operators' monitoring of the wet end area by describing its dynamic conditions, whilst automatically controlling and balancing chemical impacts of the stock flows (e.g., water quality, chemicals, stock quality, pulp). It helps the operators visualise and identify disturbances and faults at process start-ups by isolating causes of wet-end problems depicted on multi-dimensional display (Nuyan S., 2005: 15). The SKF Machine Analyst similarly facilitates the operators viewing the operation at a press section by identifying key changes detected (*International Paper World*, 2005b: 64-6).

Another key feature is a system-generated prediction of possible process-related outcomes given course of action. The automated pulp preparation system by the Metso Automation in 1992 captures human experience and knowledge into decision rules by learning the beaterman's control action. It identifies likely problems that can arise from a number of causes, and takes successive steps to rectify the process (Tarhonen P., 2005: 14; Forestier P. and Lang D., 2003: 26). Similarly, the broke predictive system in 1997 compares particular features of web profiles (e.g., profile defects and significant profile deviation) up the stream with other similar cases from its stored library to identify possible web break. The case library contains combinations of cases with descriptive features of past problems and relationships between solutions and outcomes. The system performs knowledge-guided induction by inferring general principles from specific examples and deviating rules based on features of past cases in forms of

decision/cluster tree. In order to learn, it separates a cluster of deviated reels from the good reels by analysing key features and clustering them into groups.

Operators can train the system to look at specific case features, by his guidance through the interface in order to specify what factors affect what outcomes of the model (Gillies L., 1997: 35). The predictive control for pH optimisation in 2005 observes and identifies possible causes of pH fluctuation from meter reading and incoming chemicals (Taylor M. *et al.*, 2005: 37). The WinGEMS process simulation by the Metso Automation in 2000 not just provides a graphical representation of the process. The simulator also evaluates both overall and specific process modifications and modes of operations based on the stored knowledge (Joore L. P. A. A. *et al.*, 2000: 55). The Factnet and SimAudit software performs a predictive troubleshoot of quality disturbance of a pulp screening process and a paper profile by simulating interrelationships between process and quality variables. The simulation conducts comparative analyses across time ranges and incorporates customisable pattern recognition on historical data in order to reflect mill-specific experience and the operators' expertise (*Paper Technology*, 2000c: 16).

The advisory decision-support system provides the operators with corrective advice towards process problems. The ABB Smart advisor system alerts the operators at existing or impending adverse condition detected once it identifies root causes of the problems associated with the products and the mechanics. It then provides the corrective advice and records the operators' actions. This eliminates the need for an extensive analysis of the process (*Paper Technology*, 2000a: 5). Likewise, the @ptitude Decision Support System from the SKF substitutes labour-intensive data collection and analysis effort with the

automated analysis. The operation takes place from identifying faults and appropriate solutions, prescribing appropriate action, capturing and retaining knowledge of the experts/professionals. By integrating data from multiple sources into a single application, the system mobilises a structured approach to capture and apply the knowledge, which enables the users to make quick decisions based on meaningful information and a pre-determined set of procedures and priorities (*International Paper World*, 2005b: 64-6).

#### **4 – Operators’ skills a in contemporary papermaking work environment**

Working with modern computerised process demands the operators’ tacit knowledge to work both in traditional fashion *and* at the computer interface. These include traditional physical skill, skill to deal with abstract information generated by the system, ability to relate process in procedural/logical fashion, and skills to work interpersonally with other production crews and system-related knowledge.

Work is mediated and its content consists of higher abstract content. This relies on conceptual skills and cognitive understanding of work process and content (Gerwin D. and Kolodny H., 1992: 195). Computerisation replaces some manual skill and efforts but makes demands on human information processing and decision-making capabilities, which calls for anticipatory control action (Buchanan D. A. and Bessant J., 1985: 292-308). The impact of computerised automation in making certain amount of work disappeared into machines requires the operators’ “abstract understanding” of work, and their corresponding cognitive demands for inference, imagination, integration, problem solving, and

mental maps to monitor and understand the process out of sight, as its embeddedness into equipments beyond the operators concrete view requires an ability to manipulate mental patterns, or by comparing the abstract system with concrete production steps (Weick K. E., 2000: 789-819; Gerwin D. and Kolodny H., 1992: 195; Baba M. L., 1991: 8-9). Moreover, the workers need to acquire procedural thinking skill, which refers to an ability to conceptually think through the process (Zuboff S., 1988: 73-6). “Workers select and reconcile right procedures out of sets of procedures,” for example, in an event of system-related anomalies and contingencies such as the lack of data, irregularity in the system, or system malfunctions (Adler P., 1986: 9-28).

The nature of work and problems encountered become more complex require familiarity with computer-generated medium in forms of information, codes or artificial language in the operations (Adler P., 1986: 9-28). Exercise of conceptual skills entails exercising of judgement rather than application of fixed rules (Hunter L. W. and Lafkas. J. J., 2003: 226). In other words, people need the tacit knowledge in working with this new degree of computer-generated abstract content. They need to become a connoisseur of abstract work. In case of an unexpected but critical event of machine breakdowns, for instance, the operators need to provide process control through computer interface when the automatic control is, at least, partially absent. The operators rely most on “relational information” in action, since relatively few points can their mental representation be checked against, and corrected by the actual process ( Weick K. E., 2000: 789-819).

In papermaking, computerisation tends to promote the abstraction of work as workers increasingly interact with symbolic objects; i.e., the computer-

mediated representations of the production process (Zuboff S., 1988: 62; Barley. S. R., 1996: 418). Advanced forms of computer automation in control and monitoring functions in pulp and paper production process places workers at greater distance from the production process. Nature of work alters: “whence workers rely on their senses to monitor the production, now monitoring is performed largely through intermediary of the machine. Once the traditional ‘beater man’ in charge of the pulp department of the machine tender in charge of the paper machine listened to the sounds of the machinery, touched and smelled the pulp.” Experience in an advanced mills since the mid 80s witnesses the operators working mainly out of control rooms where they monitor the production process on banks of computer screens (Zuboff S., 1988: 34).

Computerised work still requires operators’ exercise of traditional manual and sensory skills in direct process interaction, for example, when a field operator walks through the chemical production facility, checking the actual process running outside control room (Fischer M. and Röben P., 2002: 26-30). There is no total replacement of conceptual skills on traditional ones. As data-based reasoning is needed to diagnose the system-generated information and abstract reasoning skills perform the integration of diagnosis with both visual data and conceptual appreciation of the technology’s functioning, the operators draw as much from their previous experience and intuition as much as the conceptual and abstract understanding working with the computerised system (Zuboff S., 1985: 427; Gerwin D. and Kolodny H., 1992: 195). They mobilise abstract and sensory cues in performing anticipatory control action from distant and mediated monitoring from the actual equipment, for example, by identifying performance trends that indicate potential future problems (Buchanan D. A. and

Bessant J., 1985: 292-308). In other words, they rely on their ability to connect between direct observation and the control interface, which requires an ability to visualise the relationships in the operators mind (Gerwin D. and Kolodny H., 1992: 195).

In the paper industry, production workers preserve a residue of valuable informal, manual and experiential knowledge vital to the production process, though their traditional skills loses some of their centrality, as many mills begin to rely on sophisticated instruments that bypass workers' sensory methods of detection (Barley S. R., 1996). They lose their collective grip on production controls.<sup>7</sup> "The knowledge stays, but in the cracks. We like to keep it hidden" (Halle D., 1984; Hodson R., 1991a; Hodson R., 1991b). Although jobs working with fully automatic papermaking machine require far less manual activity, the computerisation does not lead to fully automatic production: the machinemen still act upon computer-generated information. The computer provides them with continuous information on the state of paper being produced, such as weight, wetness and thickness, but working with this information requires the workers to learn to interpret its readings and manipulate the production process (Penn R. and Scattergood H., 1985: 620-1). Though they press buttons more often than turning valves (some valves still need to be adjusted manually), their actions still presuppose knowledge and experience of paper manufacturing in order to make a correct judgement of appropriate action (Penn R. and Scattergood H., 1985: 618, 624). Intuition based on learned experience that used to support manual diagnostic skills now serves as basis to the interpretation of computer-generated representations on controls or the visual display units (VDUs) (Penn R. and Scattergood H., 1985: 619, 623). Computer assists, rather than fully controls the

production process.

Operators' intervention into such incidence is guided by their "feeling" of the running of the process (Huys R. *et al.*, 1999: 67-9). They also need to respond to potential and actual problems quickly (Majchrzak A., 1988: 99). As the stochastic events also cannot be pre-planned, responding to the process requires a large repertoire of skills the operators draw from whilst paying attention to, for example, the start-up process, monitoring the process, evaluating the process performance, trying to anticipate faults, or diagnosing the process problems (Gerwin D. and Kolodny H., 1992: 188-9). A number of interdependencies and speed of events of the integrated process means faults developed at a particular part of the process quickly escalate to the other parts (Buchanan D. A. and Bessant J., 1985: 292-308). The operators place premium on process reliability to keep it continue as much as possible. Skills and process sensitivities based on experience and intuition are needed in ensuring continuity and reliability (Weick K. E., 2000: 789-819).

Working with the automated systems involves knowing the system itself. This does not necessarily mean knowing system in a technical sense, but knowing the way to effectively interact with the systems, knowing how it works and why, and knowing when to use or not to use it. An operator in the continuous process plant has to know whether to accept computer readings of the process parameters.

Computer-mediated information makes available a wealth of process data that is distinct from workers' traditional methods of detection (Vallas S. P. and Beck J. P., 1996: 353). Since they have to learn to use the computer system to

cope with the wealth of available process information, new set skills emerge as they need to know when to accept the computer-generated information and guiding directions, or when to intervene. New kinds of system-related problems such as system irregularity and malfunctions or system not giving accurate process information emerge (Adler P., 1986: 9-28; Weick K. E., 2000: 789-819). Working with computer technology requires knowledge dealing with the systems. The operators “know the system,” at a particular moment, by knowing what it is doing, why it does that, and able to assess whether it is operating properly, intervening or overriding is needed (Buchanan D. A. and Bessant J., 1985: 292-308). They need to understand how the system functions in order to identify the source of deviance (Gerwin D. and Kolodny H., 1992: 18-9). Knowledge about systems integrates formal and informal understandings about the abstract rules of automated production systems on the one hand, together with experiential understandings about concrete steps in the production process on the other (Baba M. L., 1991: 8-9).

Moreover, the workers’ system-related knowledge of plants and equipments can even become contextual and idiosyncratic (Heyes J., 2001: 555). It can take years to get to know one of the plants (Blauner R., 1968). This may consist of knowledge about the ‘quirks and peculiarities’ of the machinery, the grey area between normal operations and catastrophe, and operation shortcuts as in the chemical production process (Halle D., 1984). The workers have to mobilise these system-related skills, based on experience and intuition, in dealing with routine operations and stochastic events such as downtime. In some cases, the operators do not necessarily follow a set of instructions and procedures (Halle D., 1984). For example, the operators at a computer control interface at a

pigment manufacturing plant choose between setting the process parameter setpoints or override them when the controlled parameter strays beyond its preset tolerance limit, if they know that faulty sensors activates the automatic alarm (Buchanan D. A. and Bessant J., 1985).

*Communication, interpersonal, and processual skills:* Computerised work is more interpersonal. Computerisation of the chemical production process requires staffs' better technical understanding of the production process, alongside their ability to communicate with colleagues (Mason and Wagner, 1994: 65). Advanced computer systems place higher responsibility on workers, as they place higher reliance on human intervention, interdependency, cooperation and shared responsibility in dealing with the integrated process (Fischer M. and Röben P., 2002). that has become speedier and more interdependent (Buchanan and Bessant, 1985). Although the computer reduces total number of errors in the work process, its ability to speed up work pace and integrate with other computerised process lead to potentially higher cost of errors (Adler P., 1986: 9-28). The automatic process optimiser at a chemical steam cracker plant in early 2000s, for example, places human operators at greater distance from the actual process running by reducing the need for direct process involvement; yet, the stochastic events associated with it tend to be more complex and require higher level of operators' skills to deal with (Fischer M. and Röben P., 2002). Computerisation often leads to decentralisation and work teams of multi-skilled workers to understand the total operation of the plant (Burriss B. H., 1998: 147). People need to relate their process with others. "Reliance on common databases, for example, calls for bank clerk's data input accuracy and the social skills for effective teamwork" The stochastic and continuous nature is

“integrative by nature and demands corresponding level of integration and coordination from the social and support systems” (Adler P., 1986: 9-28; Gerwin D. and Kolodny H., 1992: 187). Its demand for fast and effective rectifying response leads to, for example, the organisation of operators’ roles to include team arrangements to benefit from their variously distributed experience and capabilities, and decentralised decision-making structure for local discretion and quicker response. (Gerwin D. and Kolodny H., 1992: 188). Teams or workgroups use formal and informal knowledge and experience to deal with complex problems that arise from discrepancy between automated process and actual production process (Baba M. L., 1991: 8-9). This requires the operators’ social and communication skills to communicate with other staffs in explaining, identifying, tracing, or diagnosing process problems (Buchanan D. A. and Bessant J., 1985: 292-308).

### **Conclusion**

The first section describes nature of work of production crews in paper-making process. Work content is complex and continuous: ie, the nature of challenges is often non-routine and work covers various continuous parts from pulping to producing paper sheet. The production is under responsibilities of multiple production personnels in production team. Each is responsible for specific process that requires specific tacit knowledge.

The next section explains impacts of computer technology on work and skills in broader and paper-making contexts. The computer raises threshold of skills required in performing work as it eliminates lower-level jobs, routine and repetitive process and simpler errors. Humans workers focus attention on more

difficult aspects of their jobs—higher-level problem solving and communication with other workers, whereas the computer does not eliminate the need for knowledge underlying the routine work. There is the case for skill bifurcation. As the technological impact leads to upskilling, focus on performance of specific task in a static way has resulted in deskilling.

In papermaking, the computer automates control and monitoring tasks performed by operation workers, freeing them from physical and mental tasks. Their roles involve supervising the automated process through control interface, and solving problems that are beyond the system's capability. Consequently, the technology creates distance between the operators and process, and process that is stochastic and continuous. The workers work from control room at control interface mainly with system-generated information, supervising routine operations punctuated with unpredictable disturbances that demands full attention, such as break downs and product faults.

This section explained the development of computerised automation in paper making. Early control loop and sequential automatic programming posed limited control feature as they lacked adaptive and learning capabilities and ability to account for process dynamics of later multivariable controls. Interests to merge islands of computer led to early integration of control systems to create database of production data across mill's divisions. Subsequent technology cultivated the modern multivariable controls to integrate real-time process information and controls, whilst later development has focused on efficient integration and expandability.

Modern control systems have led to information processing that approaches

exercise of tacit knowledge. The automation has increasingly been capable of higher-level and non-routine problem-solving experiential-based learning and adapting to various forms of disturbances. An application to support decision-making has been to assist operators' identifying and solving process issues by providing process diagnosis, troubleshoot, prediction, simulation and corrective advice, in addition to providing referential and consultative resources. As a result, operators exercise their skills in working on top of these smarter tools.

In addition to mastery of work with system-generated abstract information at control interface, modern paper making requires operators' traditional physical-sensory skills and logical understanding of process. Operators also possess behavioural understanding of the system. The entire production process under team responsibility necessitates effective communication with other production crews.

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<sup>1</sup> These are phenomenon that took place since early 1980s.

<sup>2</sup> This is typically 200m long, 30m high, and 20m wide.

<sup>3</sup> The difference between production and maintenance skills is reflected in both the manner of skill acquisition and inter-skill pay differentials. See Penn and Scattergood (1988).

<sup>4</sup> Zuboff (1988) calls this an *intellective* skill. It is distinctive from the *action-centred* skill, which relies on the physical-sensory capability.

<sup>5</sup> This is based on an empirical study of paper-mills in the U.S. context.

<sup>6</sup> This is a feature called "soft sensors" by industrial practitioners.

<sup>7</sup> Computer also opens the way to inter-occupational conflict over expanding analytical functions between production workers, process engineers and technically trained supervisors. See Vallas S. P. (2001; 17); Holmes J. (1997; 11); and Blauner R. (1964): The judgement in interpreting computer-generated information and the capability in writing and maintaining software configurations of the latter has become increasingly important.

## **Chapter 5: Mobilising Tacit Knowledge**

### **Introduction**

This chapter reports empirical findings of a study of paper making of *what* tacit knowledge there is and *how* the TK is exercised at critical phase of production. The chapter is divided into two parts. The first starts with brief introduction to the nature of papermaking, and it describe grade changing as a critical incident. We then describe the computerised technology that controls the papermaking process, and specifically supervises grade changing. What follows is the operators' involvement with the grade-changing process, the nature of activities and skills involved.

The second part looks into the roles and activities of key grades of production workers, the beaterman and the machineman, at various stages of grade changing. There are four stages: preparation for the change; manual start to the change; supervision of the automated process; and manual intervention at process disturbance. This section explores what the critical operators' action is with the process and the corresponding skill content.

Instead of having the control system take responsibility away from the operators, which happens for lower-level tasks, the finding reveals that the operators possess a hierarchy of skills ranging from their background knowledge of the process to skills in working with the system. This is consistent with Polanyi's notion that it is important to think of skills holistically.

### **1 – Papermaking, technology and tacit knowledge**

This first part of the chapter outlines the characteristics of paper-making

process and grade changing as a critical incident. It introduces the control technology involved with the part of the production process responsible for the grade change.

Paper making is operated in a continuous real-time environment with several uncontrollable variables external to the control strategy that disturb a web of interacting process parameters. According to one respondent, the paper industry is “one of the most difficult to implement a fully-functioning computerised process control system.” This results in the control and monitoring system being capable of substituting for the operators’ physical and mental involvement with lower-level process control and supervisory tasks. “The computer does a good job, but not the right job,” according to a machineman. Successfully deploying the computerised automatic process control system mandatorily requires integrating the users’ “internal experience,” or, in other words, their tacit knowledge to work with the system.

Changing the production grade is critical to the papermaking. This involves work at stock preparation and at the paper machine. Grade changing is a major cause of process and product variation: it disturbs automatic production flows, breaking down production routines, requiring the production workers’ tacit skills to cope with. Nor is grade changing a rare event. Mills can change grade 42-46 times a week. Each change can take 45 minutes to an hour. Some grades may be made for no more than an hour until the next change is needed.

The grade change is the focus of this inquiry. Implementing a quick change through the process control system is critical to making money for paper mills. It is the task of papermakers to meet the production goal of producing acceptable

paper at the greatest speed and the lowest costs, time and waste.<sup>1</sup> They have to ensure the automated production process is working properly, by being “eyes and ears of the process” looking for disturbances that are beyond the system’s supervisory capacity, and making judgement where to carry out manual interventions. The operators make inferences from the control interface – textual, numeric and graphical representations of current process state on computer screens – and interact through generic input methods using computer keyboards and mice. These visual representations serve as their “windows to the process,” according to one respondent. They act as a starting point for the operators’ involvement with an actual production run.

One key success element of grade changing is to make it as simple as possible, with minimal change to the previous grade profile, whilst producing acceptable paper. As a machineman has put it:

“Anything that can be fixed, ... we will keep it the same. We don’t need to change them. ... I am not going to move anything that doesn’t have to be moved. There are more things on moving on the machine on the change. It doesn’t need to be moved.”

(interview with the machineman)

The continuous-process nature of papermaking has caused the production of previous grade to result in the paper machine at given production state (e.g., profiles, chemical flows, left-overs, attributes of physical/mechanical condition). Different products have different furnish, stocks, and pulps. Changing different types of dyes and chemicals to shift from producing one grade to the next cause changes to a whole set of interacting production parameters. The operators have to take into consideration a given state of the machine settings, chemical flows, left-overs and mechanical conditions, etc., in making a new grade.

At the control room, process control technology takes a form of the distributed control system (DCS). See Appendix 1 for pictures of the computer interface in the control room. The MeasureX DaVinci is the smart integrated control system for the paper machine. The DaVinci was introduced to the market in 2004. The control is customarily tailored to meet the mill's and fine-tuned to the machineman's personal needs. At the stock preparation, there are the early 1990s ALCONT and the 1980s E-Vision process visibility counterpart. The control room consists of computer screens, keyboards, and other non-computerised gauges. These consist of a display devoted to the DaVinci; two displays for the ALCONT or a display for the E-Vision at some control rooms without the ALCONT; a display showing the Quality Information System (QIS), which logs all the profile settings of the previous grades; and another display for the fault detection system at the end of paper machine. The Appendix 2 shows screenshots of the ALCONT and the DaVinci control systems. The control rooms are tidy and quiet, though the equipments are not new or necessarily clean. The machineman and the beaterman are among the most present in the room thanks to their direct responsibility. They also communicate with other production crews. These are usually the drierman, the machine assistant and the production manager. They would engage in telephone conversations and face-to-face discussions at the control room in order to obtain shared understanding of the process and the problems. The other crews occasionally visit the control room to check by themselves the process information displayed at the computer screens.

The stock preparation area is the "pre-wet end" or pre-paper machine activity, which involves pulping, recycling, blending and refining. The focus is

on the beaterman's responsibility in blending (cooking) before the stock is sent to the headbox onto the wire at the paper machine. This then becomes the machineman's responsibility. At the paper machine, grade changing marks the transition from one production stage to the next. This leads to variation in process parameters, and paper profiles, especially with colours. The machineman's responsibility is then to steer through this change in order to meet the production targets.

The beaterman and machineman steer the production process by working at the control interface in conjunction to the actual process behind it. They often commented that "This is a mental job. ... There is so much ground to cover." The process includes preparing for the grade change, and the operators' supervising the automated process. It also requires their manual intervention as they spot a problem and decide to take the automatic control off to manually intervene in the process. It is likely for the changing production grade to produce an interval of waste paper. As the system is incapable of adequately responding to contingencies external to its capability, the consequence is the paper that does not match any desirable specification. This is where the machineman finds his manual steering skill delivering more efficient and effective performance.

Steering the production process is a heuristic process of meeting the production goal of making acceptable paper at the greatest speed and the lowest cost, and spotting process anomaly to address problems and intervene (Polanyi M., 1964: 21-31). As there are many factors that affect the quality of paper, the production workers have to be able to steer the process through these sets of interacting variables. The production process, as their object of experience, is locked within networks of interrelations and mutual involvement (Smith B.,

1988: 6). The system-generated information works as “signs,” which represent that object. The operators “take into account a host of rapidly changing clues” in responding to process issues (Polanyi M., 1969b: 114; Polanyi M., 1958: 18, 73, 103-4, 132-3).

The operators make inferences *from* the system-generated information—abstract cue—to the actual production process. Since we rely on our awareness of the first term for actively and intentionally attending to the second term, the operators rely on their awareness of the process “behind it” (the first term) to steer the production process (the second term), by dwelling in an unspecifiable conglomeration of subsidiary clues to bear upon the object of focal attention (Polanyi M., 1966: 86; Polanyi M., 1968b: 23; Polanyi M., 1967c: 9-13; Polanyi M., 1969d: 167). The information works as signs to actual physical process. With subsidiary awareness that supports an interpretation of these signs (i.e., background knowledge and experience) allows the operators to grasp their meaning. They make the “tacit inference” as they interpret this information to make-sense of the real-world phenomenon (Polanyi M., 1967b: 301-25). The interpreted account is then subsidiarily relied upon, among other subsidiary clues, as pointers in an integrative act towards the focal object of running the papermaking process (Polanyi M., 1967c: 12, 24-5).

The information is the operators’ marginal clues in various modes of integration: preparing for grade recipe, supervising the automatic process, making judgement before manual intervention, identifying faults, fault finding, etc. According to one respondent, the typical way he makes use of the information is as follows:

“The trend that I’ve shown you earlier, whatever is away from the target I can find it. I can find out where it is away from the target, and how far it has been away from the target. Then we will see the range of the target, how far it can make mistake, or just stay away from the target as expected. We will see whether the variable goes away in the way that we have expected or not. Now we have to explore the reason why.”

(interview with the machineman)

It is worth nothing that the recent technology has further facilitated the users’ ability to make inference from the abstract data to the real process. It facilitates the machineman’s better imagination of the production state. The “ALCONT” as a DCS is the computerised control and monitoring for the pre-wet end process of blending and refining, which allows the users to see a graphical representation of the process. This includes, but is not limited to, machine chest level, refiners, and furnishing. The system also allows them to control the process. To look at the production trends or paper profiles: such as, weight and moisture, or to change the production set point can be done by button control at the computer interface.

“If they want to change to a set point, they just go in and drag through. You’ve got to bring the stuff down, and drag it, and then, put the set point that you key them all in and put the other ones.”

(interview with the software engineer)

Or to provide a representation, a viewing of the process,

“... for the ALCONT, you can move around where you want to go to choose them. So, you go quicker. You can go click on whatever there is. Just click a button and it will bring a level on that loop. I can take it off the control for one or two. I can look at trends. ... It shows you a level of where you are. I could take that out, and change the valve. Put the valve to 20% and do whatever you know, it’s there.”

(interview with the software engineer)

In Polanyi's term, the system-generated abstract information is a product of an explicit operation, as a result of system's calculation based on its programmed code, or algorithm (Prosch H., 1986: 88). It requires incorporating our personal element into its use, the tacit coefficients, in order to find it meaningful (Prosch H., 1986: 76-7).

The subsidiary clues of these abstract signs are the operators' background knowledge of the actual process and the system-related knowledge. The operators combine direct experience with the physical process (sensory) and understanding of the production process (logical) to form their knowledge of the actual process. Its significance cannot be over-emphasised, and is often echoed by the following:

“Because that's on the wire, you've got to go up there and feel it, and look at it, things like that.”

“[in changing the setpoint myself] I could make manual move on that and go up and have a look, have a feel of what it looks like at that end and control it that way, you know.”

(interview with the machineman)

“You need the understanding of the process. And that allows you to apply that understanding and logic to solve any problem. And if you don't understand the process of what you're trying to do, then you'll struggle.”

(interview with the production manager)

Moreover, at older mills, this process knowledge has been handed down generation to generation.

Without the actual process knowledge that performs in the background, the operators only rely on their interpretation of abstract information. This is often the case for the relatively less experienced production workers, who get along by consulting instruction manuals. The operators then only rely on articulated rules.

Although this involves some degree of tacit knowledge, this TK reflects their being proficient merely at applying these rules: their understanding is still detached from the real process. Several of the cues that make sense to the experienced operators appear abstract and featureless to relative novices (Polanyi M., 1969d: 168). In most cases, they can only handle the process in absence of stochastic events.

“I think you’ll find that people who don’t know [understand the actual process running] are ok when everything is working. But when things go wrong, because they’re used to the computer doing it for them, if you don’t have the experience to understand what the process is doing, you can get into trouble. So, you need both [the process knowledge and skills working with the computer].”

(interview with the production manager)

“Some people get started and they don’t know what they are doing, just follow numbers. ... If you don’t know what you are doing, you still could get it done by just follow the ABCD. You wouldn’t know what you are doing. But you’ll get it to work. ...The manual said, “Press this button, and that button.” I think you can do it from the manual. It gives instructions. ... He doesn’t need to know what the pipe goes to where, or what’s doing what. If you have the basic idea like what I’m showing you ... [like] this line goes in here and here; that’s the blend to maintain the level. That’s enough to understand. You have a manual telling you to start this and that button. That’s enough. ... All started by pressing one button there.”

(interview with the machineman)

Further, steering the process requires the operators’ acquaintance with the behavioural aspect of the control system (system-related knowledge). They have to be able to notice malfunctions in any part of the system, and not to take information cues generated by the system for granted. Papermaking skills can even become machine-specific. Only by direct experience working with a particular system or machine can the operators learn the system’s behaviour. This is related to the direct experience at a particular control system. Familiar

system's behaviour, knowing what works and what does not, is part of the operators' accumulated cues of the system's behaviour patterns associated with their reactions. The skilled operators know where the automatic control system falls short, and are able to take short-cut to the system (Smith B., 1988: 5).

Steering the process also involves co-ordinating with other production crews, the operators relate the process under their supervision with those of others'. Their common understanding is facilitated by possessing knowledge of the same comprehensive entity—i.e., the knowledge of how one part of the production process relates to the others (Polanyi M., 1961b: 458-70).

Co-ordination also involves the production workers communicating with one another. Sequences of integration—sense-giving and sense-reading—take place in this communication process. The sender first sense-reads by experiencing meaning of the particular issue, then sense-gives to the receiver by composing a verbal account of his experience. The receiver sense-reads, or interprets, this verbal account to reproduce the experience (Polanyi M., 1969a: 186). The subsidiary knowledge is brought into focus and formulated as explicit knowledge, which requires the tacit knowledge of the receiver's part for joint comprehension (Polanyi M., 1958: 261-4). That is, only by possessing the process understanding (of the actual process knowledge) can the operators make sense of what has been verbalised and so communicate with others.

The operators exercise steering skills in dealing with production issues the system is incapable of tackling by working around the problem. Given several process disturbances that could take place during the grade change, the operators often have to “workaround” the control system in order to satisfy, or to get as

close as possible to, the production goals. It is the machineman's skilful steering that allows a quick and smooth grade changing and the beaterman's skilful mixing of ingredients and his provision of the appropriate furnish required to match production state at the machineman's paper machine. This helps minimise costs associated with downtime, and waste paper.

Working around is the "knack" of papermaking. It involves delivering novel solutions to process problems, by taking alternative routes from the standard. It is built on an ability to improvise. By working around, the operators do whatever it takes to produce the paper with acceptable quality at the lowest cost. It takes various combinations of subsidiary cues and their integration to arrive at the focal cues to overcome contingencies. The ability to work around is based on the operators' accumulated experience in interacting with process and control systems. The operators usually work around to overcome the control system's limitations in dealing with process disturbance, though it is not uncommon for the workaround to improve general process efficiency that is superior to the system's own performance. The majority of workarounds involves initiating change in one area to affect or offset others. It tends to be a temporary fix: once the operators intervene in the process, they observe impacts, and once they are satisfied, they then revert the process back to automatic state. In doing so, the operators have to be able to correctly sequence and time the impact. They also voluntarily ignore certain process impacts or tolerate parametric deviation from normal practice.

This section has described a number of factors that affect the papermaking process and their interaction with the automated control system from complete control of the grade changes. Recent control system innovations have facilitated



describes roles, responsibility and action of the beaterman and the machineman in interacting with the process at each distinct stage. The empirical also highlights the case of colour-related problem as a good exemplification of issues facing the operators.

The beaterman's responsibility at stock preparation is to ensure the process can provide proper furnish, chemicals and dyes for the grade to be sent up to the headbox onto the wire at the papermaking machine. This is the blending process. He makes sure the grade page and process page are set up, and everything in the physical process, e.g., pump, is running as the machineman requires. The beaterman manually adjusts the automatically-controlled setpoints, when necessary.

Achieving the right blend is vital to meet production objective, as using recycled pulps helps lower costs but can also compromise quality.

Further, blending is the pre-wet end process from pulping that involves blending—mixing—the new (virgin) pulp with old recycled pulp of waste paper, sometimes called “broke,” other ingredients; such as, chemicals (“fillers”), dyes, and water. The process involves the mixture of pulps, broke, dye, clay, and chemicals such as the OBA <sup>2</sup>. Blending is often described as “cooking.” There are many aspects of interactions among chemicals and blends that change the effects of the dyes.

Although the beaterman controls the process through a computer interface, he needs to understand and memorise all differences among each ingredient and end product; mixtures such as, pulp, dyes, chemicals and broke. He possesses part-specific knowledge of each ingredient, interactions among chemicals, and

physical features of each kind of paper. His processual understanding of the chemicals and blend is equally vital, as he knows how these variables interact in actual production; such as the effects of dyes and paper brightness. This knowledge performs subsidiarily in the background as the beaterman engages in the focal act of blending. Its significance cannot be overemphasised, as a respondent once commented that:

“... there are so many products, so much to remember—it’s unbelievable. ... [We got] sizing, dyes, chalk, broke, and pulp. ... It’s not just dyes, clay, broke and other chemicals [like] chalk. All mixed together and they do different things. I try to get them right, and it’s quite tricky.”

(interview with the beaterman)

Challenging issues facing the beaterman involves the blending process for different grades of paper, each requires different ingredients. The challenge is “to get them right” and this requires the operator’s unique skills, in order to get the mixture right. For instance, the beaterman has to determine the right proportion of mixes between the new virgin pulp and recycled pulp (broke), by considering the colour of the end product, the colour of the broke, dyes and the impacts of other chemicals. Chalk, for example, can affect brightness. Yet, there is no fixed formula for mixtures of chemicals—such as, OBA, dyes, or clay—into the stock, which varies by the amount of broke<sup>3</sup>. The aim is to achieve a balance. To offset chemical reactions of the furnish, other production crews may decide to workaroud by altering the “pulp recipe” of certain grades.

Further, the beaterman exercises his heuristic judgement to achieve the best compromise among quality, costs and time spent on changing the grade from one to the next. For instance, he must decide whether to alter the furnish during temporary single-wire run, as the production of the single-wire grade does not

require the furnish as bright as that of the twin-wire. However, altering the furnish only temporarily to achieve optimal single-wire quality does not justify extra costs associated with downtime and production of waste paper from such change. In this case, it is possible to compromise the paper quality as the beaterman is able to use the same ingredients in producing acceptable paper of both grades. According to one respondent,

“Because we’re going back to the single wire, the furnish should be changed. The furnish of the twin-wire with a brighter furnish; the furnish of the single-wire grade, it’s the same stuff, but not as bright. I’ve told them to stay on the bright one because we’re not staying on this single-wire furnish very long. So it’s no point mocking about with the furnish. It’s too much to do. ... It’ll be ok.”

(interview with the beaterman)

The beaterman also intergrates all other processes that lead to the blend chest, by co-ordinating with other production crews in all other areas. This requires his knowledge of the process, and his ability to teamwork and communicate with others. Teamwork and communication skills allow for synchronisation of the beaterman’s process to others’ before his.

“I need to make sure the guys are ok up the salvos, make sure they put the right recipe on; make sure the broke guy puts the right broke. Then I check the clay tanks. It’s constant check and check and everything, you got to make sure everything—your dyes are there: your dye tanks, pulps. You got to make sure you put dyes in place. ... I’ve got [guys] at the salvos. They make up the pulp-recipe. And the broke guy should make up for the recycled paper. They cut the recycled paper. And I need the sort of recycled paper for the grade I am on. ... For them to know what I need, they have to be experienced. ... They have to put in what I actually have to put in. They have to know what I need.”

(interview with the beaterman)

The incident requires shared understanding of a current state of the production run and a production target among the beaterman, and production

workers at the salvo pulper and broke refiner. These personnel need to put the right mix pulp recipe and recycled paper of raw material to properly cater for the beating stage where all ingredients are mixed. The common understanding allows for an effective co-ordination, where the sense-giving and sense-reading activities take place.

Since grade changing results in process disturbance at the paper machine, it is the machineman's task to steer through this change. The process needs the machineman's manual steering the process to the point where parametric fluctuation is minimal and the actual paper profile approach the target. Switching to the automatic control whilst profile is fluctuating maintains the fluctuation. The machineman switches on the automatic control also when he is unwilling to further risk destabilising the process, which will take longer to steer it back to a desirable steady state. In a "steady run," the automatic system takes control of the process, the machineman monitors important parameters—such as weight, moisture, and colour—and trends, keying in data for the next grade and colour change.

Preparing for a grade change, the machineman conceives steps needed to produce the targeted paper profile at the right time.

He makes inferences from system-generated information to become aware of the current production stage. The system provides guidelines of how to reach a new production target, given current production state. He looks for the information—thereby, integrating process cues—of current production state and aim target: specified production specs, machine settings and the time to start the new grade. The machineman also refers to previous production records by

looking at the previous production data of the same grade; wet-end parameters such as pulp, chemicals, refiner settings; physical specifications such as weight, smoothness, moisture, colour; or machine settings such as speed. In effect, he performs a semiotic reading *towards* the production departure point by an interpretation of the system information.

The machineman examines the Quality Information System (QIS), a system that logs the previous good run settings for every grade. This allows the operators to consider historical data of key production parameters. These key variables include the top/bottom wire left–right position, stock flow, slice tight and vacuum settings, etc. Often, the machineman averages up values of production settings; for example;

“Every variable here ... I could click on that. I could have a graph. That’s the last hundred times that roll was made. So I can keep it here. We made it [the speed] at 150, 145, and 166. They are good run settings. I’ll get the average up. The average speed for that grade is made at 159. For speed, I could use that information setting [of] 159. I know it could be made at 159.”

(interview with the machineman)

He is able to judge from experience whether the average speed of these previous “good run” settings are appropriate and whether any further adjustment is needed. An understanding how the production parameters are evolved as they reach the target allows him to decide what and how much tolerance is accepted during a transition.

The machineman exercises discretion in interpreting data of the previous good production run. Since the aim is to minimise process disturbance, he needs to look into each production parameter of the previous, current and target grade and make any necessary alteration.

“I’ll print off that page, you get a print out of it. I’ll go through it and select the way they build on important parameters that I think I’ll need [in order to] make that grade. I’ll take over the page there, and I will call up for the MeasureX system for the grade change.”

“I will try matching variables there to variables there. Then, I will think about where I am just now and where I am going to. Is it too big a jump? Should I do it slow or faster? Or to do it in a hurry? Then I will carry out the change once I can put all information together.”

(interview with the machineman)

As he looks through the record, there is a working tacit process as he selectively decides which parameter to remain unchanged and by how much to change the others. His experience serves as a basis where each value is judged. Because every production is different, previous production figures, target profiles and state of the paper machine all serve as his subsidiary cues to speculate the best possible solution.

The machineman looks for the “balance” at the set up of grade specifications. He aims for the best compromise between cost and quality, as the production state needs to develop from that of the previous grade. For instance, a machineman explains the “balance” with respect to smoothness specification.

“We’ll have a balance how everything meets specification. ... We also have a smoothness specification to be met as well. What we’ll decide whether it’s calender, with pressure in the paper, or calender with heat. We can change heat on the calender, and it smoothens the paper, [by] compressing it. ... The thinner we’re making the paper, the smoother. That’s how we generally make paper. [That is] Only within the limits [of] the smoothness specification.”

(interview with the machineman)

Initiating the grade change involves communication between the machineman and other production crews on a telephone. He would periodically

speak with the beaterman. During the conversation, he looks at the screen as he converses. Underlying this is the machineman's ability to communicate: to relate his area of responsibility with that of other team members along the production line.

“If I increase the production speed, then I have to re-assess the time we give to the salvo pulper and the beaterman for changes. So, everytime I make the change of the production, I have to tell them “I’m going faster now, so I’ll be finishing quicker. There’s going to be changes earlier.” Everything that makes change in the production I will tell them. There will be changes in many areas. I am always working with the team. We have to understand the speed which changes the production rate on the machine.”

(interview with the machineman)

Thus, the machineman considers amount of time needed for the pulper and the refiner to adjust to the new grade, given the faster speed. They gradually alter the furnish towards a new target before the new production schedule, to avoid lengthy downtime producing excessive broke. The machineman sense-gives to the beaterman and the refineman his understanding of the speed and the upstream impact this causes. The sense-readers then understands what the new speed means for them by relating this articulate account to their experience in pulping and refining in order to make adjustment in accordance.

Blending involves manually starting the process, feeding the machine, getting the machine running and settling the flow before activating an automatic control which maintains the right ratio at the right constant flow of mixtures.<sup>4</sup>

Starting the system involves manually adjusting the pulp flows through valves, and manually maintaining the proportional blend, or mix, level. Start the blending requires steering skills of the operator to achieve consistent flows of all the ingredients, and chemicals at the right blend proportion. The beaterman

approaches this control process through a computer interface. He uses the information on the screen to adjust balance mixtures. The ability to infer from the on-screen information to the actual/physical production run is based on his background knowledge. This can be tricky and is something to be addressed by the beaterman's unique skills. That is,

“The tricky part is to get it to “settle” so that you’ll get a consistent flow.”

(interview with the machineman)

Because there are number of variables that can affect the blend, some of which are external to the control system. The beaterman needs to make the right hypothesis (of the source of disturbance), taking from both the abstract and sensory cues of the disturbance based on his background process and react quickly through the control interface.

Colour is one critical parameter. Any factor related to the production process affects the colour. According to one respondent: “Everything can affect colours [which include colours], but the colour cannot affect anything.”<sup>5</sup> The preparation of stock to meet colour specification involves achieving the right mixture of ingredients. The key is to balance. The colour aspect of blending demands the operators' knowledge of the chemicals' feature.

The process is started manually, and then programmed into automatic control system. The control system works by having the operators' input of setpoints. The computer then controls and feeds the variable reading, from scanner, back down the loop of specified setpoints, making necessary adjustment to other stock and flow parameters.

“As soon as you put in your change parameters, the system tunes the change. As soon as you put in your change

parameters, it will calculate what needs in the way of parameters on the machine: how much stock it needs; how much steam it needs. What it does is to say “Right! I am down here. I need to go there.” To go there, I need XYZ amounts of additives. It calculates that figure from machine parameters there at a time.”

(interview with the software engineer)

Starting the blend process for the right colour, the beaterman works manually through the control interface to get the desired colour before putting on the automatic control, by adjusting dye and chemical valves and their pump speed and taking the computer reading of the colour. According to a beaterman:

“This is the colour window. It’s made for LAB: L is how deep or clean/dirty the paper looks; B value is how blue or yellow; A value is how green or red. These dyes are mixed together; you’re trying obviously get all in the middle. To achieve that, you have to have the right dye mixture. ... [The system] tells you where the colour is, but you have to adjust it.”

(interview with the beaterman)

Doing so involves the beaterman’s relating the dye flows, stock flows and their levels in the blending chest, which depends on the amount of broke blended with virgin pulp. According to a beaterman:

“Because this [the chest] is so full now, I only have to open this valve, actually breaks into there. So, this chest will come down, this will fill up, and gives a little more room. I don’t have much room left.”

(interview with the beaterman)

The beaterman thus needs to balance the chemicals, dyes and the pulp, in order to mix the right colour. For instance, the recycled pulp needs bleaching; overdoing it could result in rejecting the paper. Balancing sometimes requires the beaterman to workaroud the process.

It is not straightforward to go from one colour to the next; it sometimes

involves offsetting chemical impacts on the sheet.

“[The management] goes from pure grade onto a very bright grade, or a bright grade onto a pure grade—it is hard to go from one to another. It’s very difficult, sometimes you are over an hour trying to get the right colour, because you try to kill the system: you’re trying to kill the yellow, or the brightness or the OBA. It’s quite hard to do.”

(interview with the beaterman)

In this case, the beaterman can only use pure virgin pulp to produce security grade paper, such as cheques. Further, the OBA<sup>6</sup> cannot be used. For the chemicals added into the system gives different reactions, in case of the OBA it yields sub-optimal quality. It is his skill to balance the chemical reactions. Any contamination of the OBA from previous grade must be offset by addition of other chemicals, such as a “broke wedge.”

### **Supervising an automatic process**

Once on automatic control, the system maintains the flow and mix at the right percentages. It takes control of the flows of ingredients from the blending chest to the paper machine. The system takes into consideration the speed of the papermachine and how much time it takes until the stock will reach the wet end, and what adjustment the system requires, with different profile variations.

“It will automatically open that valve as from the salvo to the refiner chest. ... It’ll automatically start all these motors. It’ll automatically put that flow to the pipe. That 26% valve in there: 391 litre/minute. ... That’s the pulp system—starting the blend. That’s the broke system, al started by pressing one button there. I’ll start all this line to the machine chest: start that pump and open that valve, that will send it up the headboxes, to the machine. So, you got the stuffs on the machine, coming on the wire. Then you can feed the machine.”

(interview with the machineman)

For paper colour, the system adjusts the dye flows, taking colour readings

at the scanner.

“The paper at certain colours, but what you’ve brought up the machine is much deeper than that. That’s the same colour, but it can look/appear deeper, or darker. So [it] takes the speed of the pump back, putting the same amount of dyes in. So, that brings it back to the point it doesn’t look so deep. It’s quite clever.”

(interview with the beaterman)

At the papermachine, the control system is capable of performing minor automatic grade changing. That is, the system can supervise the process with minimal alteration in the chemical content, and without disturbing the control algorithm.

Similar to grade changing, the automatic control system is designed to take care of the colour change process from start to finish.

“The shade changes, the way it does is that it’ll calculate. It’s basically looking at where you are, where it’s going to and calculates how much dyes. It basically calculates the setpoint, put dyes to the setpoint, and adjusts the ramp as it goes. ... It then waits a period of time, so the dyes flow down the machine. The scanners then read the reading. The scanner says “Right! I’ve the reading steady, I’ve the same from so many scans.” Or it’ll say “No! I will keep on scanning it.” until eventually there’s no point in changing and calculate the new setpoints.”

(interview with the software engineer)

The process involves the machineman’s keying in setpoints and monitoring the automatic process. He decides to intervene only at external disturbances (e.g., stuck dyes, muddy water). With process disturbance external to the control algorithm, the system is unable to reach the target profile. The machineman’s responsibility is then to exercise their knowledge addressing these issues.

“If I have the information correctly going in [to the system], it should be able to calculate and do it. If it can’t, there’re some external factors, it’s the operators

knowledge. So, you can't get rid of the guy. You still needs the knowledge there.”

(interview with the software engineer)

For weight control, the automatic control system adjusts key variables such as stock flow to maintain weight target setpoint. The basis weight also has its effect on other parameters, moisture, calliper, and thickness, whose interaction are calculated. For every time that the parameter fluctuates, the system makes gradual adjustment by cascading the effects.

“We put in the setpoint and say “Right! I want the sheet of the paper to be 200 grams.” Then, what it does is, it then controls back and feds it back down the loop to the basis weight value, which then will adjust the stock. So, instead of the operator putting in setpoints for the stock flow, the system has calculated the new setpoint all the time, cascading it down. So, that's kind of your basic real level of control.”

(interview with the software engineer)

Colour is one of the sensitive issues facing end customers' perceptions. A lot of rejections are caused by colour-related issues. Producing precise and consistent colour is “where the big saving is made,” according to one respondent.

Colour measurement from the sensory equipment is capable of greater precision beyond human's sensory; i.e., eyes. “It would be hard for me to visually notice that [i.e., minor colour variation] with my eyes. ... The computer is a lot more accurate than the physical eyes.” Colour is measured in terms of the L, A, and B values, and other parameters such as luminance, brightness and fluorescence.<sup>7</sup> For there are many factors affect colours, and parameters that interact with one another, the control strategy attempts to take these interactions into calculation as much as possible. Some dyes, for instance, interact with each other: the yellow dye, which also has red feature (L-A value), impacts the B value at the same time.

Like the grade change, the control system allows for automatic colour, or shade, change. The machineman's task is to steer the production process through this change at the computer interface. An automatic operation logs details of current production state: dyes, base sheets, and the L, A, and B values. It knows the types of dyes and their dilution value so that it can calculate the interactions between the dyes and colours at any given concentration value.

Identifying the cause of colour faults is difficult and requires considerable background experiential knowledge. To be aware of the physical process helps the machineman to identify issues external to the system's awareness. This takes place when the machineman manually steps in to take control.

Factors that affect colour consist of, but are not limited to: moisture level, weight/thickness of the sheet, compression of sheet to calender and starches, thickness of callipers, chemical contents (such as ash), dilution of dyes, broke content, previous grade making, or even water quality. The quality of retention of the dyes, chemicals, or pulp, may be sub-optimal; the quality of water may be poor or the water can become muddy; or the dye may stick onto the wire, for instance. The system cannot take all these factors into calculation.

It is critical the beaterman understands how the control works. The system keeps calculating for new dye flow setpoints, using scanner reading at the end of the paper machine, until it reaches the target.

“The process once sees that then asks itself “How far away is my error on the L, A, and B value?” If from outside my error, I need to calculate a new set of dye flow. So, it goes away, doing calculation to quickly get to the new setpoint and sends it down the machine. It does the same things again, wait until it [the paper] is coming down, keeps the scanning away, says right I'm stable. I'm within certain values to the L-A-B. It will keep going through that loop.”

(interview with the software engineer)

With automatic control, the beaterman exercises his judgement when *not* to intervene in the process, regardless of the way the system steers the adjustment.

He only concerns himself with what it finally achieves.

“They’ll see the same thing on an auto grade change, and I’ll say to that guy “It doesn’t matter what happens in-between. You’re given two points: it’s what happens from here to here, a relevant, as long as it gets to here at a given time. That’s what happens.”

(interview with the software engineer)

Without proper understanding, the beaterman’s undue intervention may rather distract the process from optimal production.

“For you see a grade change but I’ve seen mills when a grade change takes place and moisture goes really high. It’s ramping the speed, it’s ramping stock on. The moisture goes high and the guys keep trying to change that, and taking automatic control off and do it manually. ... It’s where it gets in the end that counts and not how it does it. ... Colours are very much like that and ... they’ll say “I wouldn’t have made that move.” And then you’ll get the price for taking the control off.”

(interview with the software engineer)

However, it is worth nothing that a brain behind the control system is a product of explicit operation. It performs only as far as what is programmable and what is measurable by sensory equipments. When it is not aware of additional dye being put in a water tank, the beaterman adds extra setpoints as a counterbalance to their impact. For instance, he puts extra pump speed to make up for additional amount of water to mix dyes.

“This shows how much the pump speed of the dye is, [of] the OBA, ... [and] the overall pump speed of the dye. ... The material handling system comes with the dyes I need. ... Then I got a tank of water that I added the dye to manually. It doesn’t come with the make-up; I have to make that up as well.”

(interview with the beaterman)

The operators' ability to draw inference from the information generated from the control system as the "windows to the process" is a key starting point for identifying the cause of colour-related problems. For instance, issues with retention and stuck dyes are reflected as changes on weight, moisture, and colour for a period of duration. Although the control system cannot pinpoint the cause of sub-optimal colour profile, it is the machineman's experience and skill that infer from behaviours of these parameters.

"That's experience! That's why you need the operator. For example, you know the chemicals going in. Chemicals need water carrier to put it down to the machine. But for example, when the water drops off, you'll get chemicals going in ... and then have adverse effects on the paper. You may see that the weight or moisture changes because that chemicals going in as a concentrate. ... We'll see maybe after 20 minutes of these blips. Then, you'll realise usually a chemical things that doses in, you'll see a timing, you'll see it, maybe up to 20 minutes of what's in the process."

(interview with the software engineer)

A temporal surge in weight and moisture reading signals excessive dose of dyes on the sheet. An experience operator is able to infer from this pattern of change the same way we perceive coherence of a single object amid other changing clues. His experience is a platform (past integration that becomes the subsidiary awareness) that, in a semiotic process, connects the surge in weight and moisture profiles (abstract signs as the subsidiary awareness) with the conception that it is due to inadequate flow of water, which results in dyes stuck on the sheet (focal awareness).

Similarly, there are different reasons behind the higher ratio of water:dye flows on a control-room display.

“[Normally] when the dyes are increasing and going up far too high, the dye would get watered down. I went to there and have the actual look to see the dye has taken up. It’s making up dyes; instead of putting, says, 10% dye with 90% water, it’s putting no dye but 100% water, making the dye very weak. I’ll pick up on that to notice when the pump is increasing a lot of water than what we would normally run up, you get to know from the experience of what the pump is running, most of the time with certain grades.”

(interview with the software engineer)

An increase in a ratio between water and dye flows leads the machine to conceive possible causes for this deviation. The intuition derived from water and dye ratios at specific paper grades points him to articulate the idea that this is due to colour deviation or empty dye tank.

Then it is the machineman’s responsibility, with other team members, to “hunt through and try to find out what the problem is.” Without such “windows to the process”, it would be impossible to know or it would take more time to realise the problem, or to find the solution. In that case, to look for colour faults, the production crews then have to “stand at the end of the machine and visually watch the variation of the colour.”

### **Manual intervention**

A significant grade changing involving changes in the chemical contents often involves the machineman’s manual control, since the goal of papermaking is to produce acceptable paper at the lowest cost and the greatest speed. It is not uncommon for the machineman to, for example, try to manually increase the speed.

“We work on the basis that we work as much as we can get. We have the standard speed. You don’t just get that standard speed: you try to get beyond the standard speed to reach your production target.”

(interview with the machineman)

Transition at the grade change usually demands the operators' manual intervention to the automatic control process, which involves workaround. This is to improve process efficiency, and to deal with process disturbance and system-related anomalies. By being able to "workaround," the system-related knowledge, and the background physical process knowledge function as subsidiary clues as they "tend" the machine. The machineman justifies impact of his skills by knowledge of parts and relationship among parameters that interact one another.

He sometimes decides to manually intervene in the automated process at profile fluctuations. In certain instances, setting a new weight setpoint at grade change causes short-term variation to other parameters. The control system confuses this temporary disturbance with a persistent impact, trying to correct the situation by constantly chasing other parametric setpoints. The machineman, aware of this limitation, takes the automatic control off and aims only at one target profile, letting other parameters adjust accordingly.

"For example, the weight. And ... it takes 149 seconds for the time that basically the stock is asked to make that change until it reaches the real scanner, then to the real machine. So, if you have disturbance and within that time scales, the control could get to the situation where it's chasing it. Because it's a very short-term variation, and every now and again that short-term variation coming down the machine, scanner comes across and might catch a high part of the variation. So, it takes the stock off, then, the next time they come, the scanner picks up the lower part of the variation. So, you get in the situation where it constantly moving the value up to chase that short-term variation."

(interview with the machineman)

Underlying this action is the machineman's processual view of production

run and how the system's limitation (that it is unaware of the time a new stock takes before it reaches the wire) affects the automated performance. Knowledge of a behavioural aspect, that the scanner catches the highest and lowest part of the variation, is key to identify when the automatic control is not doing the right job. The importance of the system-related knowledge cannot be overemphasised, according to the respondent:

“These [production] figures are adjusted by the computer incrementally to precise number. But it's how much you move it at once. The computer will say if I would have to go at 25 right now, and I'm at 21, it'll go like that: peak, and bottom, then smaller peak and bottom, until it reaches the target. Suddenly, the machine, other trends, would go up and down.”

(interview with the machineman)

Once the problem is identified, the machineman decides to do the following:

“You need to take the system off, and basically, just lock the value position and let it. ... It is critical to get good time conscience in the control in this system.”

(interview with the machineman)

An ability to take the control off, and “just lock the value position and let it” presupposes conceptual mastery of the process run outside the control room. The control interface becomes instrumental to achieve settled chemical flows: in place of senses and muscles in hammering nails or bicycle-riding, the machineman relies on the meaning derived from numerical value and temporal movement of the weight parameters in order to achieve desirable flows. This is an exercise of the tacit skill with the right timing, according to the respondent:

“It's much easier to do it a bit a time, as long as you still make acceptable paper. You can still make little changes and you won't even notice anything on the trend. If you do big changes, you will.”

(interview with the machineman)

The system-related knowledge and the background process knowledge also allow the machineman to relate to actual production run at process invisibility or delayed process feedback. For instance, whilst machine speed is not instantly updated, the machineman's awareness of the steam pressure allows him to correctly estimate the actual machine speed and the new setpoints to offset the deviation.

“In a perfect world, it will be updated, so we get grade settings all the time. But things change on the machine, for instance, the machine we operated has got more steam pressure, which suddenly we've started running a bit quicker than we used to.”

“For some reasons, the quality isn't right, then, I have to ignore [the figures] here and there, go to look, and see what's wrong—whether I need more or less speed.”

“Then I'll tell the computer. I'll go and see. Instead of running [on automatic] 300 grams, I run [at] 285 grams. I have to put the new set point in. ... They will automatically move to a new set point.”

(interview with the machineman)

Behavioural knowledge of the control system and understanding of the papermaking process allow the machineman to identify system malfunctions from an erratic form of data. For example, faulty sensors give faulty parameter readings causes all calculations to be wrong, as one machineman has put it:

“Once it doesn't work, ... there was one of these numbers not working right, and because it takes parts with the thickness and flow and calculate. ... There could be faulty consistency readings, then it'll give bad numbers, and screwed everything out.”

(interview with the machineman)

The key to steering the process is to keep parameters steady at raw

material change. For instance, to produce watermark paper, it is crucial to keep porosity within a narrow range of values, since too high porosity impairs watermark visibility. Because adding broke content increases the porosity, more refining is needed. The machineman thus lowers the machine speed to match conditions at refining. Critical to successful manoeuvre lies in the temporality; by properly timing the pace the altered stocks moves from the refiner to the papermachine. Accordingly,

“Everything really has got to be in the steady area. Or else it’ll give you a lot of hell. ... We’ll take the broke out with the batch, the pulp, the porosity is then up. So, when we’re running the refiner, you’ll start slowing the machine back. And you sorta chase things. If you are on watermark paper, to keep the watermark, you’ve got to have everything run pretty steady. If things are swinging about, and changing, like the porosity, that affects the wet line. ... If the porosity comes up, the wet line will go back. It’ll lose the water things like that.”

(interview with the machineman)

The operators may sometimes find their manual workaround leads to a faster control response. For instance, to increase sheet moisture, a machineman decides to take the automatic control off, by temporarily increasing the setpoints for higher stream before reverting to the original setpoints and the automatic control system.

“See that moisture, it has been [set at] 6%. If that suddenly went up to 8%, I could automatically increase the stream. Sometimes it’s a wee bit slow to respond, so I’ll put on manual, increasing the setpoint, get it to come. ... I’ll bring that back in a wee bit. ... You can make a manual move, it’s quicker than this sort of react. ... Once I made a manual move, watch it stays over 2 or 3 minutes, watch what that’s doing, and then put it back to control again.”

(interview with the machineman)

Working around the process may involve the machineman in ignoring certain profile setting at the system. This happens when the standard machine

setting cannot deliver desirable product quality; for instance, the right thickness:

“We can’t get the right thickness. We can’t get the right heat in the calenders. These are things that we work around. We got to tend the machine, if you like, to get what we want.”

(interview with the machineman)

For example, with different raw material, by adhering to the standard machine settings from the QIS log, the machineman cannot produce desirable paper. That means it is impossible to produce the target grade at the normal profile settings. By referring to his previous experience or tacit knowledge of producing an alternative grade, he is able to improvise with alternative recipe in order to produce acceptable paper.

“It’s not always [that we follow the QIS] because, for some reasons, the company cannot get the pulp to make the paper we want. Different pulps have different properties. For some reasons, it makes me a part on the calender of the machine, giving a quality issue. ... In the main, for a change like this, if I would be going from LFF300 to LFF350 [the production code], I 99.9% know by experience if I do the preparation and do the grade change there, it will be all right. The only thing that is going to stop that is that an unseen fault comes up., you know it, dirt or faults.”

(interview with the machineman)

By relying on his subsidiary knowledge of the chemical interactions among ingredients, the machineman decides to voluntarily allow for extra chemical effects. He adds extra ash content to the original spec to offset other chemical effects on colour during the grade change.

“[A]t the moment, it runs 26% ash, the spec is at 24 target. I know it’s running at 26 at the moment to help the colour. So, I’m not going to go at 24, because it’s going to affect the colour during the change. So, I keep that the same as well. It’s still specs off-limit. I’ve changed the set point to 26%. Ash is the chalk, helping with whiteness—they’ve got different kinds—one for whiteness, one for colour.”

(interview with the machineman)

The subsidiary knowledge consists of chemical features of ash and the way it interacts with colour dyes. The ash, as chalk, helps increase brightness, which in turn affects the overall sheet colour, the L-A-B readings. Here the machineman decides to maintain higher level of ash than the spec to achieve higher brightness, and the right colour.

Alongside processual understanding, it is equally important the machineman knows the way each ingredient affects the overall production and reasons behind the way the computer delivers information:

“... there're sets of chemicals that you overdosed will do certain things to the colour, and if you have the wrong broke it will do certain things to the colour. If you have wrong colour on the sheet, that would do certain things to the colour. Depending on what grade you've come from, so there was going to have certain colour from the previous grade. So, the system will say you are too yellow, but why you are too yellow you have to understand, and there maybe 4 or 5.”

(interview with the production manager)

What also matters are specific knowledge of a characteristic of each dye and physical conditions it has been kept.

“[T]he way you have the system set up with metering pumps; you now mills has the potential in effect to drop a dye into water carriers and put that to the machine.”

(interview with the machineman)

“Also, you've got to take into effect that when you put dyes into the system, some dyes will hold to the stock a lot better than others.” ... “The top coil dyes area really bad for falling through the wire. ... These are things in the process that the mill put the dyes in the process at given points, because the dye needs to fix itself to the stock and fibre. For example, you got chemicals that go in the retention that it retains. It's stuck into your paper. If that retention drops away slightly and falls through, the end at the wire will be different as well.”

“Someone can dilute the dye differently, says 75%. In reality, it should be 70%. So everytime a person sets amount of the dyes, it’s [the automatic system] gonna take more dyes than asked for. So it’ll chase. ... The colour will be over-compensated, and the control wouldn’t be as good.”

(interview with the software engineer)

In addition to the chemical interactions, the papermaking process involves a whole web of production parameters, of which one affects the other. To master this understanding, the machineman refers to his background knowledge of the actual process. For example, the loaded slice affects how the paper looks. Its level reflects how much water is mixed to the paper; it pressurises the flow box allowing for better dilution and dispersion of the pulp and better sheet formation—smoother, more dispersed and even. At times, he is unable to exactly match the loaded slice value to the log.

“That’s what we made before: 22.5, it’s acceptable paper. ... We are currently at 21-21.5. I know the last time we have made 22.5. I am quite happy with 21.5. I know it is not going to affect the smoothness, the calliper, or other physical things or the colour. All it affects is how the sheet looks.”

(interview with the machineman)

Although the machineman cannot afford to match the loaded slice from the previous record target, given prior production state the machine has moved from, that he is still confident he has steered a smooth transition.

“It depends on where I was. I might decide the previous making [to 25] that’s too big a jump, some of these settings. And if I think I can make a decent quality by not moving everything on the machine as much, I’ll do that. And, then, slowly improve it as I am making it once we’ve started making good paper. We’ll improve it. But for this, from 21 to 22.5, it’s right side of setting of that change from [the basis weight of] 280 to 325.”

(interview with the machineman)

To work around the machineman improvises by setting the loaded slice value lower from target. The aim is to avoid abrupt change, which increases broke. The smooth transition then proceeds with gradually increasing the slice to approach the original target. Doing so requires the machineman to know the way changes in loaded slice value affects a whole web of parameters, something mastered only thorough experience. He knows that to adjust the setpoint in a way that is not going to significantly disturb key paper profiles (sheet colours, smoothness, callipers (thickness)) it must concur with change in sheet basis weight at the same rate.

The transition ends where the process “settles down”: that is, once it reaches the production state where parameters stop fluctuating. Larger profile changes takes longer until the process settles. Therefore, it is critical the machineman steers the changing process with as minimal time and adjustments as possible, in achieving the minimum production costs and errors, and at the greatest speed.

“22.5 looks right to me. ... And I’ll say, “OK, it’s going to take a couple of minutes to do that to settle down.” If I’m moving to 25, it takes longer: lots of things would cling on the machine when everything is moving. It would [affect other variables] while it’s changing. Once it’s got there and everything is settled down, that’s fine. But it’ll take you half an hour to get there. But I can go half way in 10 minutes and still making acceptable paper and improve it later on. ... What I’m looking for is the balance of quality and how long it takes to change. It saves a lot of money. ... As long as the paper is fine, and once you’ve made good paper, you could make little adjustment to improve it further.”

(interview with the machineman)

Identifying the causes of faults also involves communication with other team crews. When actual production parameters stay away from the target, the

machineman responds by both working through the computer interface and having the production team checking the actual production facilities. He starts questioning the cause of anomaly, verbalising his process knowledge. As one machineman puts it,

“I work with them all [the production team]. It depends on who noticed the problem first. Usually, when a variable stays away from the target, I want to know the reason why.”

“I would say “Ah!, there’s something wrong here.” ... You would know that the porosity, as I say, you would know that the spec is going up and up and up, and you would see changes: the consistency of the stock would change. ... The rest of the figures are in the specification, but porosity aren’t. ... We’re running the consistency for anything of 3-4.5. That would change because obviously where the refiner is not working properly, the consistency there would get thicker. And I would see that. But my first line of communication would be the guy up the stairs.”

(interview with the machineman)

When the refiner does not work properly, the machineman knows that this causes upward erratic movement of porosity and stock consistency value (the stock getting thicker) from semiotic reading as he makes inferences from the porosity and consistency readings. He then has to relate his process with other crews in the refining area.

This second part confirms that the background process knowledge and the ability to logically relate to the process are inevitable to the operators’ skill set. Together these allow them to draw inferences from the computer interface in the control room to the actual production process, and to effectively respond to issues at various stages of process transition. From the data, these are: “cooking” ingredients, consulting production log, manual adjusting stock flows, supervising the automated process, spotting on problem and manually intervene the process

by working around the problem to meet the production goal.

### **Conclusion**

A number of factors that affect the papermaking process hinders the ability of automated control system from taking complete control of grade changes. Implement the grade change involves work at computer interface at both stock preparation and papermachine. Recent control system has facilitated the “triggering” of the operators’ tacit knowledge in making inference from system-generated information to the actual process. Besides, the operators rely on their tacit knowledge of the actual production process, system-related behaviour, and skills to logically work through the process, co-ordinate tasks and communicate with other production crews. This is consistent with Polanyi. Since any performance has its root in tacit knowledge, it is inevitable that working with the computer interface requires the operators’ tacit knowledge of each constituent (Polanyi M., (1967b: 4). Together, they enable the operators to successfully steer the process by preparing for grade change, manually starting change process before activating any auto-pilot control, supervising automatic process, then identifying any process problem and making decision to manually intervene.

Critical to successfully steering the production process, both the beaterman and the machineman workaround the process to overcome system limitation in response to process issues. Working around is the key problem-solving skill in the computerised papermaking. Contrary to simply following the system-related instruction, the operators’ tacit knowledge allows them to perform problem-solving skill in an innovative way. It allows them to meet the objective of paper production of producing the best acceptable paper at the lowest costs.

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<sup>1</sup> These include: machineman, beaterman and other production workers.

<sup>2</sup> the Optical Brightening Agent

<sup>3</sup> the recycled pulp

<sup>4</sup> By the ALCONT, in this case.

<sup>5</sup> interview with the software engineer.

<sup>6</sup> The OBA is the chemical that brightens the paper. It is often cheaper to apply OBA than to use the bright virgin pulp, especially when one can use the recycled pulp. Production of certain premium grades, however, requires only the use of the bright virgin pulps.

<sup>7</sup> L & A is red and green; B is yellow and blue

## **Chapter 6: Conclusion**

This research has examined the exercise of tacit skills in the computer-mediated paper-making environment. The research mobilised Michael Polanyi's philosophy of tacit knowledge as a basis for an interpretation. The methodology aims at interpreting meaning embedded with the subject's experience, in order to understand the tacit knowledge, based on qualitative interview and observation techniques. Prior to the field work, we conducted the secondary research into an existing body of literatures, in order to secure background understanding of the case.

This thesis consists of six main chapters. Chapter 1 outlined the thesis. The context to the fieldwork, the theoretical framework and the methodology were introduced. The chapter also provided information of the research site.

Chapter 2 described a theoretical basis for an interpretation of the phenomenon that follows. It justified the centrality of tacit knowledge to *all* kinds of skilful performances and its potentiality for problem-solving. The text was divided into two parts. The first proposed that the tacit knowledge underlay all exercises of knowledge and skills, illustrated in light of an informal process of the logic of tacit integration. Mobilising intelligent effort and delivering skilful performance involved the integration of specifiable and non-specifiable subsidiary elements. These served as clues, a base from which we directed our focal effort. This applied to all ranges of activities from skilful physical activities, uses of tools, to embracing intellectual frameworks. Here, we typified the tacit knowledge based on its explicit expression into the physical, semiotics and intellectual. This contributed to the understanding of how Polanyi's thought

could be applied. The tacit knowledge resulted from building up of the experience. The exercise tacit knowledge also led to a heuristic act that encompassed problem-solving. The experience served as resource, which allowed an expert to deal with diverse problem situations in a novel manner. As the experience expanded, his approach became increasingly subtle, adaptive and does not necessarily follow a logical pattern.

The first part also explained how Polanyi's thought was influenced by others. Notably, the thinking of Merleau-Ponty and Dilthey contributed to Polanyi's idea on the gestalt view of the tacit knowledge and the instrumental roles of body and mind in the tacit integration. Rothschild's idea contributed to Polanyi's idea on interpersonal communication.

The second part presented viability of Polanyi's idea in a philosophical debate. The critics were divided into two main arguments. The first denied personal elements in beliefs, experience and intellectual framework. The second view asserted the tacit knowledge only became useful only if their elements and process could be fully articulated. These are important for an absence of the tacit knowledge ruled out the possibility of the heuristic act. The section illustrated an impossible feat of articulating all parts and processes of the tacit knowledge, and that the personal element became inevitable for psychological facts that formed parts of the beliefs, experience and scientific practice.

Chapter 3 presented a methodological consideration. Owing to a close analogy between the tacit knowledge and the experience, we proposed a study of the meaningful experience to produce a truth-like statement—a thick description—of the subject's perspective that belonged to a particular issue. Multiple

triangulated methods were applied to interpret a set of meaningful experience, expressed as narrations and interactions. Our approach also stressed researcher's employed the "human instruments" to secure both direct and indirect tacit knowledge of the phenomenon. This called for a secondary research into an existing body of literature, and a qualitative fieldwork based on interviews and observation techniques. Breakdown of the routine activities provides an occasion for the study the tacit knowledge as people articulate what has normally been taken for granted. This research applied the critical incident interviews to identify the critical phase–events and behaviours–that were described or observed to a significantly diverged outcome from the general aim of a particular activity. We then adopted the qualitative interview and observation techniques to collect the articulated account of the experience . The interview encouraged respondents to tell stories of their experience. The researcher learned about context by personal contact and discussion. Taking field notes from the observation allowed the researcher to identify recurring observed patterns. The narration were then broken down into statements, sequences and action units, to be classified into skill categories.

Introduction to the case of paper-making was described in chapter 4. Paper industry was a continuous process manufacturing where the whole production generally covered the entire stream from pulping to making dry sheet of paper, whose process involved an interaction of interdependent parameters. Work was craft-based and subject to more than one production crew. Goal of paper-making was to produce acceptable paper quality at greatest speed and lowest cost. Work content involved working at a control interface as "windows to the process" to identify process anomaly and often to solve complex and non-routine problems.

Each production team member was responsible for certain parts of the process. The computer technology automated–substituted–tasks normally performed by the operators in control and monitoring functions. Such computerised and automated environment has transformed the paper-making into a stochastic process, marked by routine operations punctuated with periods of non-routine variances that accompany high attentiveness and activity. It aided their problem-solving by prompting articulated “triggers” to the tacit knowledge as process visibility, diagnosis and troubleshooting information, and knowledge resources.

Early computerisation had made the process visible in forms of system-generated abstract information. Together with the integration of control and information systems, it had broadened the operators' supervising responsibility; hence, their additional skill requirement. Recent computer technology imposed finer control schemes and tighter integration. One notable feature was the information-processing capability that approached our exercise of tacit knowledge in experiential-based learning and problem-solving. This has led to the system's active decision support as process diagnosis, troubleshoot, simulation, prediction, corrective advice, and consultative referential resources. As a result, the work demands additional skill hierarchy to work "on top" of these capabilities. Tacit knowledge, or skills, required for successful paper-making includes mastery of work with the system-generated abstract information, traditional physical-sensory skills, processual understanding of the paper-making, knowledge on behavioural aspects of the system, and capability to effectively communicate with other production crews based on common understanding.

Chapter 5 reported our finding. The grade changing was critical to the

paper-making process and mills' profitability of paper mills, due to major process disturbance and output variation it caused. The goal was for the beaterman and the machineman—the key production workers—to achieve a smooth transition to minimise broke, and to maximise acceptable paper production. The operators “steered” the process through the control interface by making inferences *from* the system-generated information *to* the actual production process. They communicated with other team crews and, in some cases, directly interacted with the physical process. They initiated and supervised the grade change, identifying and solving process-related issues, as they made inference of the abstract cues. Critical to a successful grade change was working around the process and control system to overcome its limitation and to improve overall process efficiency.

Working around involved delivering novel solutions by taking alternative problem-solving routes from the standard. The operators did whatever it took to produce acceptable quality of paper at lowest cost, based on their ability to time and sequence impacts. The workaround tended to be a temporary fix during the operators' manual intervention before they reverted back to the automatic state. Its ability depends on their accrued experience of the computerised work environment *in conjunction to* their direct exposure with the physical process. This points to the crucial role of the traditional physical-sensory know-how, in the work dealing mainly with the abstract content.

This provided a contradictory argument to the deskilling thesis that the technology had rendered them obsolete. From our finding, this traditional know-how served instead as a critical component assisting the workers in the background. It was impossible that the abstract reasoning alone enabled the

production crews to exercise their problem-solving skills in an effective manner. The workaround became the craft for the computerised work process, whose applicability depends on the mastery of abstract reasoning *in connection to* the background physical-sensory know-how.

Several cited work in this thesis on the skills in papermaking did not explicitly address the definition of tacit knowledge and skills, with a notable exception of Zuboff (1988) who provided the definition of the *intellective* skill, which replaced the *action-centred* skill. Although Zuboff does not adopt the deskilling view, her finding tends to neglect the salience of the traditional know-how. That the intellective skills is central to running paper machines in the computer-mediated environment, which exclusively rely on abstract cues, explicit reasoning, and procedural thinking, is far from adequate. Our finding opposed the creation of the “doubly abstract world” in exercising paper-making skills (See Zuboff S. (1988: 87)). Instead of constructing abstract mental images out of memory and imagination to refer to concrete reality, the finding suggests the background experience of the physical production process is key to become an effective papermaker. Yet, the differing conclusion might reflect difference between the US and the UK contexts. Greater product standardisation and sheer scale of the industry have incentivised the US mills to stay uniformly current with the newer technologies, as opposed to incremental investment in several of the UK mills. (Magee G. B., 2009: 42).

Another contribution of this research was the application of the thoughts of Michael Polanyi to explain the phenomenon, where the work was mediated by symbolic representation. The methodological choices combined the critical incident technique with the thickly descriptive method. The tacit knowledge was

made visible to the researcher at the breakdown of the routine events. The critical incident technique helped us identify this disruption. However, the limitation resided in the full applicability of our proposed method. The granted level of access to the field, and the time frame posed a constrain on the extent to which the observation was conducted.

Further research possibilities consists of an exploration of the critical skills in other computer-mediated work settings. The existence of the non-formalisable know-how warrants the inevitability of the peculiar form of problem-solving. The comparative studies among the manufacturing industries and between the blue-collar and the white-collar industries provides an ample opportunity to contribute to the greater understanding of the unique human skills.

**Appendix 1: Pictures of the Control Room**



**Appendix 2: Screenshots of the Control Systems**





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