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Three senses of paradigm in scenario methodology: A preliminary framework and systematic approach for using intuitive logics scenarios to change mental models and improve strategic decision-making in situations of discontinuity

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ABSTRACT

This article outlines the objectives, activities, and achievements of using intuitive logics scenarios to improve strategic decision-making in situations of discontinuity. Pierre Wack's work at Royal Dutch/Shell illustrates the use of exploratory, reframing, and decision scenarios to change the mental models of decision-makers in advance of the 1973 oil crisis. Thomas S. Kuhn's *The Structure of Scientific Revolutions* offers a promising theoretical account of paradigm shifts in science, but its application is limited by the ambiguity of the concept of paradigm. Margaret Masterman's distinction of three senses of paradigm – introduced as construct paradigm, worldview paradigm, and action paradigm – clarifies and extends these accounts to support a preliminary framework and systematic approach. Overall, this investigation expands our understanding of strategic decision-making as guided not only by analytic achievements and developmental investigations but also by discontinuous breaks that can be explored and addressed using scenario methodology.

Section 1 provides an introduction and literature review. Section 2 examines the scenarios developed at Royal Dutch/Shell. Section 3 summarizes Kuhn's new image of science, clarified by Masterman's three senses of paradigm in Section 4. Section 5 presents implications for scenario methodology, followed by conclusions and areas for research in Section 6.

1. The objectives and methods of effective intuitive logics scenarios

Intuitive logics (IL) scenarios[1] are used in organizational development, strategic management, policy development, and other fields to explore the "'limits of possibility' for the future" (Wright et al., 2013). Relying upon multiple and diverse perspectives, in-depth analysis of uncertainties, and the application of plausibility-based, "intuitive logics," IL scenarios are designed "to overcome the limits of linear, reductionist, and deterministic thinking" by providing a way "to engage intuition, expose deeply held assumptions, and forge new and shared interpretive frames" (Wilkinson et al., 2013).

Wright et al. (2013) survey the research literature on scenario methodology to identify three objectives of effective IL scenarios. According to the authors, the first objective is "enhancing understanding… of the causal processes, connections, and logical sequences underlying events – thus uncovering how a future state of the world may unfold." The second objective, "challenging conventional thinking," is directed toward "reframe[ing] perceptions and chang[ing] the mindsets of those within organizations." The third and final objective of effective IL scenarios is "improving decision-making… to inform strategy development" (Wright et al., 2013).

The authors assert that the basic methods of IL scenarios are designed to address the first two objectives. They question the ability of scenarios to achieve the third objective, that is,

> …whether scenario methods in any form and in themselves have any causal connection with improved decision-making to inform strategy development? Or, do they merely offer a potential stimulus toward better decision-making?
>
> (Wright et al., 2013)

Answering these questions is important for setting reasonable expectations for IL scenario methodology and its applications. If IL scenarios have a causal connection[2] with improved decision-making, we

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[1] The theory and practices of intuitive logics scenarios are outlined by Schwartz (1991), Wilkinson (1995), van der Heijden (1996), and Bradfield et al. (2005).

[2] As highlighted by Derbyshire and Wright (2017), it is important to understand the nature of causality.

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must hold practitioners to that high standard and develop the field accordingly. But if IL scenarios are merely a potential stimulus to decision-making, then the responsibilities of practitioners and the scope of scenario methodology can be narrowed substantially.

1.1. A review of the research literature

The processes, criteria, and authority of decision-making are subjects of investigation in both theoretical and practice-based disciplines, ranging from centuries-old philosophical debates about the approaches, structures, and limits of knowledge[3] to emerging fields in decision sciences,[4] and best-selling books about approaches to thinking (Kahneman, 2011; Taleb, 2005; Taleb, 2007).

Within an organization, ensuring effective, strategic decision-making[5] requires grappling with issues of uncertainty (Courtney, 2001; Milliken, 1987; Walker et al., 2003), managerial cognition and mental models (Beshears and Gino, 2015; Wack, 1985a), and social, political and cultural influences on the actors and processes of decision-making (Johnson, 1988; Mintzberg, 1994). In the context of forecasting or other attempts to consider change over time, this complex set of issues becomes a dynamic mix of interrelationships, requiring assessments that extend beyond a specific decision to the underlying processes of changing (Pettigrew, 1990). As investigations expand to encompass a broader range of factors, faster rates of change, or longer periods of time, these complexities and interrelationships increase even further.

1.1.1. Analytic and developmental approaches to strategy

In the field of strategic management, the complexities of strategic decision-making are central to debates about the nature and effectiveness of strategy (Brews and Hunt, 1999; Favaro and Kleiner, 2013). Analytic approaches, such as the planning (Ansoff, 1965), rational (Peters and Waterman, 1982), and positioning (Porter, 1980; Porter, 1985) models, characterize strategy as "a progressive series of steps of goal-setting, analysis, evaluation, selection, and the planning of implementation to achieve an optimal long-term direction for the organization" (Johnson, 1988). The practice of strategy is a linear, rational, and prescriptive process in which decisions are made by senior management based on detailed, often highly precise frameworks and analyses.

In contrast, developmental approaches propose that strategy is not simply the outcome of a highly rational process, but "can best be seen as the product of the political, cognitive and cultural fabric of the organization" (Johnson, 1988). These approaches include research in adaptive learning (Mintzberg, 1973), sense-making (Weick, 1995), organizational action (Johnson, 1988), the design school (Mintzberg, 1990), managerial cognition (Gavetti et al., 2005; Tripsas and Gavetti, 2000), and capabilities- and resource-based views of the firm (Collis and Montgomery, 1995). According to these accounts, strategic decision-making is more than the search for analytical precision (Mintzberg, 1987). In actual practice, strategies emerge over time and strategic decisions are made within a particular organizational, industry and environmental context based on the cognitive maps of key players. Strategic decision-making is linked with learning, relies on tacit knowledge, and includes choices that are difficult to assess, such as commitments to long-term investments or improvements in non-tangible assets.

Despite longstanding and sometimes heated debates [e.g., Mintzberg, 1990; Ansoff, 1991], the analytic and developmental approaches to strategy are not mutually exclusive (Peters and Waterman, 1982; Johnson, 1988; Porter, 1996; Mintzberg, 1994). Recently, scholars have emphasized the need for both approaches in order to address the complexities of strategic leadership, particularly in situations of environmental uncertainty, technological disruption, or discontinuity (Brews and Hunt, 1999; Montgomery, 2012; Tushman and O'Reilly, 1996). What remains at issue are the methodological and epistemological questions of how, when, and under what authority organizational leaders should adopt each approach.

1.1.2. The use of IL scenarios in situations of uncertainty

Intuitive logics scenarios[6] are used in both analytic and developmental approaches to strategy. Within analytic approaches, corporate strategists use IL scenarios to broaden strategic perspectives and avoid surprises (Schoemaker, 1991; Porter, 1996; Millett, 2003; Meitzner and Reger, 2005). Scenario methodology provides strategic decision-makers with insight into state uncertainties [i.e., how the external world or industry might change] as well as effect and response uncertainties [i.e., how changes will affect an organization, and how decision-makers should respond (Milliken, 1987; Vecchiato and Roveda, 2010)].

In addition to broadening strategic perspectives, IL scenarios can improve the precision of (analytic-strategic) decision-making by narrowing the range of plausibility, possibility, or even predictability in ways that are not possible using established models or frameworks (Roxburgh, 2009). In some cases, scenario analysis reveals critical driving forces that are predetermined elements of the scenarios (van der Heijden, 1996; Wack, 1984), that is,

> … forces that we can anticipate with certainty, because we already see their early stages in the world today… We do not know exactly how these events will play out, or precisely when they will occur. But we can anticipate the range of possible results, and the ways in which the rules of the game may change thereafter.
>
> (Schwartz, 1991)

Similarly, there may be implications that are robust across all scenarios (Wilkinson, 1995). Identifying these predetermined elements or robust implications provides greater clarity for strategic decisions and establishes a closer link between scenarios and strategy (Vecchiato and Roveda, 2010). As yet, however, the effectiveness of scenarios in directly informing strategic decision-making remains unproven (Phadnis et al., 2015), particularly with regard to middle managers in operational positions (Millett, 2003).

In developmental approaches to strategy, IL scenarios are used both to broaden strategic perspectives and to address the limitations of established ways of thinking. The first use of scenarios complements analytic approaches to strategy; however, the second use serves as a critique. In the field of organizational development, scenarios are used to stimulate creative thinking (Garvin and Levesque, 2006), support organizational learning (Burt and Chermack, 2008; van der Heijden et al., 2002), guide strategic conversations (van der Heijden, 1996), and avoid group-think (Roxburgh, 2009). In strategic management, developmental approaches use scenarios to look beyond specific end-states to the potential paths of change (Marchais-Roubelat and Roubelat, 2015).

1.1.3. The use of IL scenarios in situations of discontinuity

As a way of exploring alternative futures, scenarios are uniquely valuable in situations of extreme uncertainty when analytic and developmental approaches fail to capture the full range of possibilities (Schoemaker, 1991). Scenarios are often used to explore situations of volatility, turbulence, disruption, and discontinuity; however, the

[3] The debates extend throughout the history of philosophy, and the implications extend well beyond philosophy. Recent academic and popular accounts include Bernstein (1983) and Herman (2013).

[4] The emerging field of decision sciences has its roots in statistics, game theory, decision analysis, data science, and behavioral research, with some approaches including sociology and psychology.

[5] The third objective of "improving decision-making: to inform strategy development" (Wright et al., 2013) is characterized hereafter as "improving strategic decision-making." This broader conception extends beyond strategy development to include all aspects of strategy formulation and implementation.

[6] For typologies of IL scenarios, see van Notten et al. (2005), Bradfield et al. (2005), and Meitzner and Reger (2005).

terminology of this work is inconsistent and ambiguous (van Notten et al., 2005). A clarification by Burt (2007) distinguishes the short-term disorder of disruption from the more fundamental shift of discontinuity, defined as a "'lack of continuity or cohesion' with past experience, bringing about a new order over time." On this account, the break from past experience caused by discontinuity is not simply ambiguity, change, volatility, turbulence, or short-term disruption, but rather, a break that brings about a new order.

In bringing about a new order, a discontinuity represents a shift in the defining, ontological structures by which we order reality (Johnson, 1988; Marchais-Roubelat and Roubelat, 2008). In such cases, both analytic and developmental approaches to strategy may be challenged or undercut (Burt, 2007), (Wack, 1985a). The steps required to identify, assess, and respond to a discontinuous break require more than simply broadening strategic perspectives or recognizing their limitations. Rather, what is needed is a change in the mental models of decision-makers: a shift to a new perspective that reflects the new order and can be translated to decision-making (Vecchiato and Roveda, 2010). Scenarios are an effective tool for exploring these ontological shifts (Marchais-Roubelat and Roubelat, 2008; Marchais-Roubelat and Roubelat, 2015; Walton, 2008; Wilkinson et al., 2013), although a change of approach may be required (Vecchiato, 2012).

1.2. The need for a systematic approach for using IL scenarios to improve decision-making

While there have been notable cases of using IL scenarios to explore situations of discontinuity or to change the mental models of decision-makers, scenario methodology still lacks a systematic account of the underlying processes:

> …while there is anecdotal evidence in the literature as to the ability of scenarios to "affect decision-makers' view of reality" the issue of "precisely how this happens and can be consistently achieved is still a mystery"
>
> Wright et al. (2013), citing Burt and Chermack, 2008

Our central question is, "how can we use IL scenarios to change the mental models of decision-makers and improve strategic decision-making?" From a methodological perspective, what are the underlying activities and processes? How can we justify these efforts epistemologically? And practically speaking, how can we create a bridge that extends from scenarios to strategy?

2. The development of decision scenarios at the Royal Dutch/Shell Group

One of the most recognized accounts of using scenarios to change mental models and improve strategic decision-making was written by Pierre Wack (1984, 1985a, 1985b), head of scenario planning in the business environment division of the Royal Dutch/Shell Group (hereafter, Shell) from 1971 to 1981.[7]

2.1. Shell planning scenarios 1970–1973

As shown in Table 1, Shell's planning activities increased steadily in the decades following World War II. Between 1945 and 1955, the planning group guided Shell's efforts to rebuild physical infrastructure destroyed in the war. During the following decade of global market expansion, planners focused on the financial analysis of large projects. The scope and time horizon of planning efforts became more detailed and comprehensive over time, culminating in Unified Planning Machinery (UPM), a computer-driven system and 6-year plan extending across the global chain of activity. The UPM guided Shell's planning efforts until 1973 when it was replaced by scenario planning.

A dramatic shift in Shell's planning efforts began in the late-1960s, prompted by an experimental study of the business environment through the year 2000. The Year 2000 study predicted the end of oil market expansion and a shift in market power from buyers to sellers. Such a shift threatened to transform the competitive structure of the oil industry (Porter, 1980), disrupting oil prices and inter-fuel competition and undercutting the predictive accuracy of Shell's planning and forecasting activities. The prospect of such a dramatic and consequential break – under Burt's (2007) classification, a discontinuity – convinced Shell's management that it "had to find a new way to plan" (Wack, 1985a).

To investigate the potential discontinuity, several operating and services groups at Shell undertook a 15-year forward look called Horizon Year Planning. At Shell Française, Pierre Wack analyzed two major uncertainties in French oil markets based on the scenario approach used by Herman Kahn and the Hudson Institute (Wack, 1984). The scenarios and other Horizon Year efforts confirmed the potential for discontinuity.

Over the next several years, Wack led a series of scenario planning efforts in Shell's central offices (Table 2). Initial exploration of the discontinuity (1970/1971) developed into an effort to reframe managers' business-as-usual worldview (1972), and finally, into a focus on changing managers' mental models of reality (1973).

In developing the 1970 scenarios for French oil markets, Pierre Wack and his team quickly found that analyzing the scenarios with the same level of detail as UPM would "almost quadruple" their workload. Instead, they used flexible simulation models and discussions with experts to "deal easily and quickly with alternatives" (Wack, 1985a). The goal was to gain a deeper understanding of the discontinuity and the interplay among uncertainties, in order to "ask better questions and develop… decision scenarios" (Wack, 1985a).

As the newly appointed head of group scenario planning in Shell's central offices, Wack designed the 1971 scenarios to explore the discontinuity on a global basis. The objectives of this work were "to give insight into the system, to identify the predetermined elements, and to perceive the connections among various forces and events driving the system" (Wack, 1985a). To represent the business-as-usual perspective, Wack included a surprise-free scenario based on managers' shared views of external and market environments. The team identified six uncertainties for further analysis "to expand the number of predetermined elements and get at the core of what remained uncertain" (Wack, 1985a).

Wack designed the 1972 scenarios to challenge managers' business-as-usual worldview by analyzing both the impact of discontinuity (A-group) and the prospects for avoidance (B-group). Detailed industry, competitor, and market analyses revealed the implausibility of avoidance, "forced Shell management to realize how disruptive the change in their world would be," and "destroyed the ground many of them had chosen to stand on" (Wack, 1985a). Senior managers shared the findings with governments of major oil-consuming countries and presented detailed industry and market analyses to the second layer of Shell management. Standing "in stark contrast" to typical, numbers-based planning sessions, the internal presentations "sparked some intellectual interest" but "like water on a stone," failed to change managers' behavior (Wack, 1985a).

In designing the 1973 scenarios (i.e., "The Rapids") Wack and his team shifted their objective from "producing a 'good' document" to "changing the image of reality in the heads of critical decision-makers" (1985a). They treated the discontinuity as predetermined, defining it as the surprise-free scenario and eliminating the B-group of avoidance scenarios. Additional scenarios were designed to "expos[*e*] and invalidat[*e*]" the obsolete worldview, using established Shell frameworks

[7] For additional accounts of the early Shell scenarios and the contributions of key players such as Jimmy Davidson and Ted Newland, see van der Heijden (1996), Cornelius, Van de Putte and Romani (2005), Jefferson and Voudouris (2011), and Wilkinson and Kupers (2013).

Table 1
Planning processes at Shell, 1945–1973.

1945–1955	Physical planning and scheduling of new facilities to keep up with post-war rebuilding efforts and global market expansion (e.g., production capacity, tankers, depots, pipelines, and refineries).
1955–1965	Detailed financial analysis of major projects.
1965	Unified Planning Machinery (UPM) annual planning system introduced for 6-year, detailed plans across the global chain of activity.
Late-1960s	UPM, supplemented by experimental studies exploring the business environment in the year 2000 to reflect long lead times for new projects. One study predicted a major discontinuity in oil markets.
1970	UPM, with 15-year Horizon Year Planning (by 12 Shell companies and sectors in London and the Hague) to explore the discontinuity. Pierre Wack experimented with scenarios for Shell Française.
1971	UPM, with experimental scenario planning conducted in Shell's central offices in London.
1972	UPM, with 1972 scenarios and detailed market analysis of the discontinuity using hard and soft data.
1973	Phasing out of UPM planning, with the extension of scenario planning throughout the group.

Source: Wack (1984, 1985a).

to illustrate the loss of substantial rents, the shift toward a low-growth environment, and the need for decentralized decision-making and strategy. To help managers construct a new model of reality, the team analyzed the impact of market changes on different functions and geographic areas, including sensitivities based on the emergence of discontinuity in different parts of the business cycle.

Less than a year after The Rapids scenarios were presented at Shell, the U. S. response to the 1973 Arab-Israeli War led to an oil embargo by OPEC, prompting a global economic crisis as oil prices rose from $3 to $12 per barrel. Shell's managers recognized the events as indicators of the end of global, economic expansion and the beginning of a market shift to supplier power. Having already explored the implications of such a scenario, they made a number of critical strategic decisions, including policies for refining investments that positioned the group to outperform industry competitors by a wide margin (van der Heijden, 1996).

2.2. The use of scenarios to change mental models and improve strategic decision-making

According to Pierre Wack (1985a), “strategies are the product of a worldview.” Only when decision-makers are able to “question their own model of reality and change it when necessary” will they be able “to come up with insights beyond their minds' previous reach” (Wack, 1985a). On this account, scenario methodology improves strategic decision-making by changing the mental models of senior leaders “when necessary.”

2.2.1. The necessary role of predetermined discontinuity[8] in changing mental models

The prospect of discontinuity in oil markets played a central role in the development and effectiveness of the Shell scenarios. Each set of scenarios was designed to explore the potential discontinuity, which was shown through the work to be predetermined. The success of The Rapids scenarios in changing the mental models of Shell's decision-makers was neither justified nor accomplished by the scenario narratives, but rather, by the detailed external, industry, market and company analyses supporting them. The scenarios served as an effective tool for changing mental models *given the prospect (later, the predetermined nature) of discontinuity*.

The Year 2000 study's identification of an impending market shift from buyer to supplier power challenged the predictive capabilities of UPM's detailed analyses and provided the impetus for a new approach to planning. Early efforts explored the potential for discontinuity in French oil markets (1970) and then on a global basis (1971). Once the discontinuity was identified as predetermined, the 1972 scenarios challenged the business-as-usual worldview by analyzing the prospects for occurrence or avoidance of the discontinuity. Finally, the 1973 decision scenarios of The Rapids treated discontinuity as the surprise-free scenario and connected to the strategic and operational frameworks of decision-makers. This final set of scenarios – derived from earlier work yet able to stand on its own – established the need, justification, and basis for a (necessary) new form of managerial judgment.

2.2.2. The realignment of the microcosm and macrocosm

In situations of predetermined discontinuity, it is not enough to challenge established models of reality or to render old worldviews obsolete. What Wack identified as decision scenarios (e.g., The Rapids) are needed to realign managers' mental models with the new reality:

> [*w*]hen a decision is good, others will say the manager has good judgment. In fact, what has really happened is that his or her mental map (‘microcosm’) matches the fundamentals of the real world [‘macrocosm’].
>
> (Wack, 1985a)

Decision scenarios “supply a vital ‘bridge’” between the macrocosm of the unfolding business environment and the microcosm of decision-makers (Wack, 1985a). Wack describes this connection as the existential effectiveness of scenarios, explained by the Japanese expression, “When there is no break, not even the thickness of a hair, between a man's vision and his action” (Wack, 1985a).

To change managerial behavior across the organization, recalibration of the macrocosm and microcosm must extend to the shared views of managers, that is, the *corporate* microcosm:

> Strategies are the product of a worldview. When the world changes, managers need to share some common view of the new world. Otherwise, decentralized strategic decisions will result in management anarchy. Scenarios express and communicate this shared view, a shared understanding of the new realities to all parts of the organization.
>
> (Wack, 1985a)

Decision scenarios realign the microcosm of managers across the organization with the new realities of the external environment, or macrocosm. In doing so, they provide the foundation for shared judgment and ensure consistency in managers' decisions and actions.

2.2.3. The activities of exploratory, reframing, and decision scenarios

In reflecting on his experiences at Shell, Wack emphasizes the need for two sets of scenarios: first-generation scenarios to structure the uncertainties and to provide a basis for judgment, and second generation scenarios (i.e., decision scenarios) to help managers re-structure their models of reality. As shown in Table 3, the three steps outlined by Wack correspond to the objectives of effective IL scenarios identified by

[8] Identification of a predetermined discontinuity [i.e., an uncertainty that is determined to occur and “bring(s) about a new order over time” (Burt, 2007)] is a rare but important task for which scenarios are well-suited given their ability to analyze and test the boundaries of a range of potentially contradictory prospects and perspectives.

Table 2
Shell scenarios, 1970–1973.

	1970 Scenarios("Horizon Year")	1971 Scenarios	1972 Scenarios	1973 Scenarios ("The Rapids")
Objective	Assess prospects for discontinuity in French oil markets.	Explore prospects for discontinuity in global markets.	Challenge the business-as-usual perspective.	Compel managers to question their mental models of reality.
"Surprise-free" scenario	N/A.	Business-as-usual: shared views of current patterns of change in the external and market environments.	None: comparison of scenarios to explore occurrence vs. avoidance of the discontinuity.	Discontinuity treated as predetermined in all scenarios.
Analyses and activities	Flexible simulation models.	External and market forces driving the oil system (e.g., industry, economic and financial forces).	Industry and competitor analysis for each scenario: volume, price, impact on individual oil producers and consumers, and inter-fuel competition.	Alternative fuels, potential accidents, negative supply elasticity.
	Expert analysis of alternatives.	National interests, government take, reserve-production, energy demand, oil imports, and political tensions of oil supply.	Presentations to build managers' insight and understanding of external and market changes (rather than to predict outcomes).	Government responses and impact on various stakeholders.
		Responses by oil producers, consumers, and companies.		Business impact on specific Shell operating groups.
				Sensitivities of impact during various phases of the business cycle.
Achievements	Confirmed the potential for discontinuity.	Identified six uncertainties for further analysis as predetermined elements.	Convinced senior management the discontinuity could not be avoided and would be extremely disruptive.	Established a bridge between the unfolding environment and the deepest concerns of decision-makers.
		Increased managers' understanding of the discontinuity, but provided no basis for decision-making.	Sparked interest among second level managers, but failed to change behavior.	

Source: Wack (1985a).

Wright et al. (2013) and the activities of what we now classify as exploratory, reframing, and decision scenarios.

The exploratory scenarios of both 1970 (Shell Française) and 1971 (Shell central offices) were designed to explore the potential for discontinuity "based on a sound analysis of reality" (Wack, 1985a). These early efforts achieved the first objective of effective IL scenarios: enhancing understanding of "causal processes, connections and logical sequences" to uncover "how a future state of the world may unfold" (Wright et al., 2013). Given the threat to Shell's strategy and planning efforts, these explorations were a necessary first step, but they were not sufficient for developing a response to the discontinuity.

The 1972 reframing scenarios provided a (new) basis for judgment and challenged conventional thinking (objective #2) through the development of A- and B-groups of scenarios. Detailed industry and competitor analyses showed the discontinuity could not be avoided, thereby invalidating the business-as-usual perspective. Although the scenarios and analyses succeeded in "refram[*ing*] perceptions" and "chang[*ing*] the mindsets" of Shell's senior executives (Wright et al., 2013), they failed to change behavior across the organization (Wack, 1985a).

The 1973 decision scenarios changed the mental models of decision-makers across the organization and improved decision-making (objective #3). Scenarios of "The Rapids" linked the realities of discontinuity (i.e., macrocosm) to the microcosm of middle managers, thereby establishing a bridge from the scenarios to managers' decisions and actions.

2.3. *The preliminary implications for scenario methodology*

The Shell scenarios of 1970–1973 are exemplars of exploratory, reframing, and decision scenarios. They illustrate the activities used to achieve the three goals of effective IL scenarios in a situation of predetermined discontinuity.

To extend this illustration into an overarching framework or systematic approach, we must understand more clearly the methods, criteria, and authority of the processes involved (Eisenhardt, 1989; Eisenhardt and Graæbner, 2007; Kuhn, 1976). As discussed below, the work of Thomas S. Kuhn uses in-depth case studies to develop a new image of science based on the activities of scientists and the underlying structures of scientific revolutions. Although Kuhn's work was developed within the history of science, it provides valuable insight into the elements of strategic decision-making and the processes for changing mental models in situations of discontinuity.

3. Thomas S. Kuhn's historical developmental method and the "new image" of science

Thomas S. Kuhn's *The Structure of Scientific Revolutions* (1962/2012) is an extended essay whose aim is, "a sketch of the quite different concept of science that can emerge from the historical record of the research activity itself." Developed through historiographic case studies of scientific discoveries, the work examines the activities and processes whereby scientific theories and practices are refined, challenged, and, in some cases, replaced by new and substantively different commitments.

Kuhn's account of scientific revolutions – in particular, his central concept of paradigm – has been used to illuminate key aspects of strategy (Denning, 2012; Dufour and Steane, 2006; Johnson, 1988; van der Heijden, 1996), scenario methodology (Burt, 2007; Marchais-Roubelat and Roubelat, 2015; Roubelat, 2006; Walton, 2008), and futures studies (Mannermaa, 1991; Slaughter, 2002; Tuomi, 2012). As the summary and analysis below suggest, these contributions can be refined and extended even further.

Table 3
Objectives and activities of the Shell scenarios, 1970–1973.

Objectives of effective IL scenarios ("what") Wright et al. (2013)	Activities of IL scenarios ("how") Wack (1985a)	Points of similarity and difference
1. Enhancing understanding: • of the causal processes, connections, and logical sequences underlying events; • thus uncovering how a future state of the world may unfold.	1. Structure the uncertainties (1970/1971 "exploratory" scenarios): • explore the interplay of uncertainties; • identify predetermined elements.	Shell's initial scenarios were developed to explore a potential discontinuity in oil markets, thus representing a special case of uncertainty.
2. Challenging conventional thinking: • reframe perceptions; • change the mindsets of those within organizations.	2. Provide a basis for judgment (1972 "reframing" scenarios): • outline potential changes in macrocosm (i.e., real world); • develop executives' understanding of the nature of uncertainties and help them come to grips with them.	Shell's refined scenarios expanded the initial account in a way that was tailored to managers' concerns and focused on developing their understanding of the challenges ahead.
3. Improving decision-making: • inform strategy development.	3. Support changes in the mental models of decision-makers (1973 "decision" scenarios, The Rapids): • change the microcosms of managers and the organization; • help managers reconstruct their mental models; • use scenarios to build a bridge to decisions and actions.	Shell's second generation scenarios reflected a different goal from the prior ones, that is, changing the mental models of decision-makers to compel different types of strategic decisions and actions.

3.1. The historical development of Kuhn's account

Although *The Structure of Scientific Revolutions* was published in 1962, its underlying issues became a research question for Kuhn fifteen years earlier, during the summer of 1947. Kuhn had returned to Harvard University from an overseas posting during World War II and was writing his Ph.D. dissertation in physics. He was asked by Harvard President James B. Conant (a chemist by training) to help develop an experimental science course for students in the humanities based on case studies of scientific discoveries.[9]

3.1.1. Kuhn's "Aristotle experience"

In preparing a case study on the development of Newtonian mechanics, Kuhn found that the preceding Aristotelian tradition provided limited support for Newton's discovery. In fact, much of what Aristotle had said about motion seemed to be wrong. Kuhn struggled to reconcile seemingly egregious errors with Aristotle's reputation as a careful observer:

> "I was sitting at my desk with the text of Aristotle's *Physics* open in front of me and with a four-colored pencil in my hand. Looking up, I gazed abstractedly out of the window of my room – the visual image is one I still retain. Suddenly, the fragments in my head sorted themselves out in a new way and fell into place together. My jaw dropped, for all at once Aristotle seemed a very good physicist indeed, but of a sort I'd never dreamed possible. *Now I could understand why he had said what he'd said, and what his authority had been.* Statements that previously seemed egregious mistakes now seemed at worst near misses within a powerful and generally successful tradition."
>
> (Kuhn, 1987)

What Kuhn later characterized as the paradigm shift from Aristotelian to Newtonian mechanics reflects a simultaneous change in fact, theory, and practice. His "Aristotle experience" revealed that Newton's conception of motion "invert[s] the ontological hierarchy of matter and quality," thereby requiring a wholesale reworking of Aristotle's theory and methods (Kuhn, 1987). As the inversion is integrated into scientific theory and practice, the emerging community of "Newtonian" scientists begins to work in a "different world," guided by assumptions, tools, and investigations that are substantively different from what they used previously (Kuhn, 2012).

Kuhn's Aristotle experience convinced him that science develops not only through cumulative, incremental additions to knowledge but also through revolutionary changes in scientific fact, theory, and practice. Kuhn dedicated his career to understanding this new image of science (Kuhn, 2012). His first step – as for Pierre Wack – was to search for the proper methodological approach.

3.1.2. Methods of exploration

In exploring scientific revolutions, Kuhn found that the shift suggested by his Aristotle experience was not evident in either historical surveys of science or scientific textbooks (Kuhn, 1961). The emerging field of internal historiography provided a promising approach: by examining the internal structures of earlier theories and practices, researchers worked to reveal historical beliefs and practices within the context of their own time (Butterfield, 1965). Through careful interpretation, they were able to correct inaccurate assumptions and the implicit biases of "Whiggish" history.

Kuhn adapted the historiographic method to examine not only the internal structure but also the external context of scientific revolutions, later describing this approach as a historical developmental perspective (Baltas et al., 1997). His early investigations spanned 15 years and extended across a wide range of areas, including the history of science, philosophy of science, sociology of science, child psychology, Gestalt psychology, and philosophy of language. One by one, Kuhn developed the four elements of his new image of science: scientific revolutions,

[9] President Conant viewed his students (i.e., veterans recently returned from World War II) as members of the rising managerial class, who soon would be responsible for government funding and corporate oversight of science. Rather than providing a historical survey of established scientific achievements, he wanted to educate them about "the various methods by which science has progressed," that is,

> [*t*]o develop in the student some understanding of the *interrelation between theory and experiment* and some comprehension of the complicated train of reasoning which connects the testing of a hypothesis with the actual experimental results.
>
> (Conant, 1957)

Adopting the case study method used by the Harvard Business School (Garvin, 2003), Conant directed Kuhn to develop case studies examining the processes and research activities underlying scientific discoveries.

anomalies, normal science, and finally, the concept of paradigm.[10] In 1962, he published *The Structure of Scientific Revolutions*.

3.2. Kuhn's new image of science

In *The Structure of Scientific Revolutions* as well as later works, Kuhn describes his new image of science in ways that are confusing and sometimes conflicting (Feyerabend, 1970; Hoyningen-Huene, 1993; Masterman, 1970). Over time, he refined, revised and even replaced some of his central concepts, acknowledging the limitations of his early publications yet continuing to insist on the key elements of his account (Kuhn, 1970).The following summary reflects these conceptual refinements.[11]

3.2.1. The puzzle-solving activities of normal science

As understood through its research practices, science is a puzzle-solving enterprise conducted by members of a community who are distinguished as such by their shared network of methodological, theoretical, and instrumental commitments. Scientists dedicate themselves to solving the complex puzzles of their field, which they generally are able to do successfully. These puzzle-solving activities of "normal science" constitute the vast majority of scientific research: individual scientists extend their knowledge and research in consistent and (usually) incremental ways, building on both the established foundations of their discipline and the work of other members of their community to advance the field.

3.2.2. The investigation of anomalies

In the course of their investigations, scientists regularly encounter anomalies, that is, observations that do not fit expected results. These anomalies are a natural outcome of solving complex puzzles. They serve as tests of scientists' puzzle-solving skills and the means by which new solutions are developed.

An anomaly can be resolved in one of three ways: 1) by correcting previous errors that led to the anomaly, 2) by revising the network of commitments in ways that are incremental, or 3) by changing some or all of the commitments in ways that challenge the integrity of the network. The first type of resolution (i.e., correcting previous errors) is especially common for young scientists learning the field. The second type of resolution (i.e., incrementally revising the network of commitments) occurs regularly as part of the continued development of a science and represents the way in which a field most often advances. As described below, the third type of resolution – challenging the integrity of the network of commitments – is much less frequent. Its extreme form (i.e., scientific revolutions) is rare, particularly in well-established fields.

3.2.3. The boundary-testing activities of extraordinary science and emergence of crisis

In some cases, an anomaly cannot be resolved easily. When an anomaly presents a sufficiently serious challenge to scientific theory or practice, members of the scientific community intensify their investigations. Interested scientists re-examine the anomalous observation, isolate it, and attempt to give it greater structure. They examine the situations in which it occurs and the factors that influence it. Gradually, they loosen the boundaries of related commitments, beginning with minor adjustments and proceeding to consequential changes, as needed.

If an anomaly persists despite continued tests and careful application of the range of commitments, and if it is sufficiently problematic for puzzle-solving, then the field may be thrown into crisis. Failed attempts to resolve an intransigent anomaly undercut the authority of the field, leading members of the scientific community to question (some of) their commitments. Shared practices diverge, as members experiment with different ways to resolve the anomaly in order to reinstate (what they consider to be) effective puzzle-solving. This is the boundary-testing of "extraordinary science."

3.2.4. The exploration of alternatives and integration with the network of commitments

As the crisis continues, scientists work to identify alternative resolutions and to incorporate them into the network of commitments. Members of the community may decide a proposed resolution creates too much upheaval in established approaches or reduces the overall effectiveness of the field. They note the anomaly as unresolved and return to their previous puzzle-solving activities.

Other members of the community may continue their efforts to explore the anomaly and to integrate potential resolutions into the network of commitments. This is difficult work. It is not enough simply to resolve an anomaly; a proposed resolution must be integrated into the community's shared network of methodological, theoretical and instrumental commitments. For major changes, necessary adjustments must be justified, and the revised network of commitments must be judged superior by members of the community. These debates are battles for theory choice. They may lead to a splintering within the community, with some members preferring the old network (based on certain criteria) while others prefer the new one (based on different criteria). During the debates, the commitments, criteria and even what it means to be a scientist within the field are brought into question.

3.2.5. The struggle with incommensurability and competing "ways of seeing"

As debates within a community continue, some scientists develop the old network while others extend the puzzle-solving capabilities of the new one. Such efforts may create a bridge between the two perspectives or may isolate a specific point of divergence. In some situations, the differences in commitments are so fundamental that no détente is possible. In the debates between Aristotelian and Newtonian mechanics, for example, Newton's inversion of Aristotle's ontological hierarchy of quality and matter renders the two interpretations or ways of seeing the world – and thus the criteria and approaches for analyzing it – incommensurable.

In situations of incommensurability, two groups see the world in different ways because their ontological commitments (i.e., the "facts" they investigate) cannot be reconciled.[12] These conceptual differences in ontology, or "what there is" necessarily entail epistemological differences in "how we know."

3.2.6. The resolution and achievements of scientific revolutions

As debates continue, each group uses and develops their favored approach. Over time, competing networks of commitments are tested and extended further: new puzzles are solved, new anomalies are observed, and new members of the community are brought into the field. In some cases, the two approaches continue to coexist. In other cases, one or the other approach gradually loses support as members of that community switch their allegiance or die without being replaced by members of a younger generation.

When an established network of commitments is replaced by one that is ontologically-epistemologically opposed (i.e., incommensurable), the shift represents a scientific revolution. Members of the (new) community have new "ways of seeing," which lead to new "ways of

[10] Early introductions of these concepts include Kuhn (1959) and Kuhn (1961). An initial version of the new image of science presented in *The Structure of Scientific Revolutions* is provided in Kuhn (1962).

[11] For a detailed account of the historical development of Kuhn's theories and methods, see Wayland (2003).

[12] Competing views are incommensurable if one can "see the world" only in one way or the other at a particular time. In the famous rabbit-duck illusion, for example, one can see the image as either a duck or a rabbit, but not as both at the same time (Kuhn, 1983).

working." Once these new perspectives and approaches are established, the old ways of seeing (and working) seem to be more than simply wrong or misguided. The new approach does not simply correct or refine the old one, but reinterprets it according to a different way of seeing and working in the world. Because of this (ontological-epistemological) shift, the old approach – like that of Aristotelian mechanics after Newton – now seems to reflect "egregious mistakes." As with Whiggish interpretations of history, the old approach is not simply replaced, it is effaced, and its previous coherence – along with the clarity of its legacy – is destroyed.

3.2.7. The early stages of a science

As suggested by its title, *The Structure of Scientific Revolutions* presents an account of the activities and processes underlying revolutionary shifts in the commitments of a scientific community. Kuhn's new image of science applies not only to scientific revolutions but also to the early stages of a science, that is, the research that occurs before guiding theories are developed, established, and accepted. Scientists' activities during these early stages are similar to those of periods of crisis: researchers move beyond simply testing the boundaries of established facts, theories and practices to question them and develop alternatives.

4. The nature of a paradigm

We have summarized Kuhn's new image of science without yet introducing his concept of paradigm. Kuhn developed the concept as the final, "missing element" of his account and described it as "the most novel and least understood aspect" of the work (Kuhn, 1970). It also was the most controversial.

In the early years following its publication, *The Structure of Scientific Revolutions* was praised by historians of science as presenting "a new epistemological paradigm," which revealed the previously hidden yet central role of research activities in the development of science (Hesse, 1964). In contrast, leading philosophers of science strongly rejected Kuhn's paradigm-based view as undermining the epistemological authority of science, describing his characterization of science as relativistic (Shapere, 1964), irrational (Feyerabend, 1970), "governed by mob psychology" (Lakatos, 1970), and "a danger to science and indeed, to our civilization" (Popper, 1970). Sociologists of science welcomed this disruption, praising Kuhn as "a man who did as much as anyone to destroy the authority of science" (Brown, 1997), to which the author replied, "One thing you have to understand. I am not a Kuhnian!" (Dyson, 1999).

Kuhn rejected many interpretations of his work, in particular, accusations of relativism and irrationality by philosophers and sociologists of science. In response to critics at the 1965 International Colloquium in the Philosophy of Science in London, he posited the existence of two Kuhns with similar yet consequentially different views of science (Kuhn, 1970), acknowledging that the concept of paradigm was central to the misunderstanding.

In an introduction to the fiftieth-anniversary edition of *The Structure of Scientific Revolutions* (2012), Ian Hacking notes that after five decades, much of the controversy surrounding the account has subsided, and the concepts of paradigm and paradigm shift are now "embarrassingly everywhere" (Hacking, 2012). Yet despite the ubiquity of its use, the concept of paradigm remains obscured by ambiguity and confusion, and some critics still view Kuhn's account with disdain (The Ashes of Truth, 2017).

4.1. The three senses of paradigm

At the 1965 colloquium in London, Margaret Masterman presented, "The Nature of a Paradigm" (1970), a detailed textual analysis of *The Structure of Scientific Revolutions* identifying 21 different uses of the term "paradigm." While faulting Kuhn for the ambiguity of this central concept, Masterman also faults his critics in the philosophy of science:

> …those who attack [Kuhn] have never taken the trouble to find out what [a paradigm] is. Instead, they assume without question either that a paradigm is a 'basic theory' or that it is a 'general metaphysical viewpoint'; whereas I think it is in fact quite easy to show that, in a primary sense, it cannot be either of these.
>
> (Masterman, 1970)

To clarify the concept of paradigm, Masterman groups the 21 uses into three categories (i.e., metaphysical, sociological, and construct senses of paradigm), based on their function within Kuhn's account of scientific practice. According to Masterman, the metaphysical sense of paradigm supports a *Weltanschauung*, or worldview. The sociological sense of paradigm provides a community with a locus of professional commitments or set of habits. Finally, the construct sense of paradigm functions as a crude analogy that supports puzzle-solving.[13]

In determining which sense of paradigm is primary, Masterman considers Kuhn's characterization of science as a puzzle-solving enterprise:

> …if we ask what a Kuhnian paradigm is, Kuhn's habit of multiple definitions poses a problem. If we ask, however, what a paradigm does, it becomes clear at once [assuming always the existence of normal science (i.e., the primacy of puzzle-solving)] that the construct sense of 'paradigm', and not the metaphysical sense or meta-paradigm, is the fundamental one. For only with an artefact can you solve puzzles.
>
> (Masterman, 1970)

According to Masterman, the construct sense of paradigm is the central contribution of Kuhn's work and establishes him as "one of the most important philosophers of science of our time" (1970).

4.2. The dual nature of a construct paradigm

Masterman[14] proposes that in the early stages of a science – before the other senses of paradigm are possible – a construct paradigm functions as an "actual artefact used analogically" (Masterman, 1970). This occurs through its basic property of concreteness, which adheres in two ways:

> [A construct paradigm]…is a concrete 'picture' of something, *A*, which is used analogically to describe a concrete something else, *B*.… It thus has two kinds of concreteness, not one: the concreteness which it brought with it through being a 'picture' of *A*, and the second concreteness which it has now acquired, through becoming applied to B.
>
> (Masterman, 1970)

As an actual artefact (A-concreteness), a construct paradigm establishes a picture of something (i.e., "what" it is). This originating picture lies hidden at the heart of any theory, even "an idealized scientific theory" (1970).[15] As used analogically (B-concreteness), a construct paradigm "guides and restricts the theory's

[13] The three senses of paradigm correspond to competing interpretations of Kuhn's work. Philosophers of science interpreted the concept in its metaphysical sense (i.e., as a falsifiable theory that supports a worldview), thereby rejecting the suggestion that a scientific community could select or replace its paradigm. Sociologists of science applied the sociological sense of paradigm (i.e., as shared habits or commitments), thereby praising the central role of the community of scientists. Finally, historians of science commended Kuhn on his insight into the actual practices of science, supporting the activity-based development of a construct sense of paradigm as the basis for primitive puzzle-solving.

[14] As a pioneer in computer science and linguistics at the Cambridge Language Research Unit, Masterman was attuned to the challenges of the early stages of a science. One of six students attending Ludwig Wittgenstein's (*Blue Book*) early lectures on language games at Cambridge University, she held a deep interest in how language and meaning may be established independently of theory.

[15] Masterman (1970) notes, "In fact, and in genuine and live science, the very effort to establish a 'concrete scientific achievement' has to justify itself. . . . Thus the real problem, in getting a philosophy of new science, is to describe philosophically the original trick, or device, on which the sociological paradigm (i.e., the set of habits) is itself founded."

articulation" (i.e., "how" the picture can be used to understand something else), thereby supporting its extension (Masterman, 1970). As a result,

> [*t*]he abstract entities in the resulting theory can then be doubly interpreted – as indeed in a new science they have to be – firstly A-wise, in terms of the generating analogy, and secondly B-wise (that is, operationally, and, as the theory develops, increasingly) in terms of [a particular selection of] data taken from the field to which the theory is being applied.
>
> (Masterman, 1970)

Masterman asks (but does not answer) the important question, "how does a construct paradigm become a way of seeing?", that is, how does a construct paradigm develop into a metaphysical or sociological paradigm (1970).[16] As a starting point, she suggests investigators "re-examine what is true about analogy[17] in the light of what Kuhn has shown to be true of paradigms" (1970).

4.3. The dual function of a construct paradigm

The dual nature of Masterman's construct sense of paradigm supports a dual function. In its A-concreteness as an actual artefact, concrete picture, or generating analogy, a construct paradigm functions as an ontological construct that establishes "what" it is. As a selection of data taken from the field (i.e., B-concreteness), a construct paradigm functions as an epistemological application that guides "how" it can be applied and extended further. Masterman's characterization of the dual nature of a construct paradigm thus suggests a dual function at the intersection of ontology and epistemology, that is, as an ontological-epistemological construct.

The originating and extensive power of a construct paradigm lies in this duality, as both an established, ontological foundation and an authoritative, epistemological application that supports puzzle-solving. A construct paradigm supports primitive puzzle-solving by simultaneously establishing its own ontological structure and epistemological authority. It both defines and guides activities, independent of externally-imposed boundaries. Through its dual function as an ontological-epistemological construct, a construct paradigm supports puzzle-solving in the absence of rules (e.g., periods of discovery) or when established rules are in question (e.g., periods of crisis). It establishes both the means and the authority by which members of a scientific community understand their world and operate within it.

4.4. The implications of the three senses of paradigm for Kuhn's new image of science

Kuhn's Aristotle experience suggests a new image of science: a revolutionary break from Aristotelian to Newtonian physics, or what we now can identify as an ontological-epistemological shift in the three senses of paradigm that define and guide scientific study of mechanics. Although the experience was immediate for Kuhn (he describes it as a Gestalt switch), the scientific and historiographic investigations required to identify 1) the ontological-epistemological construct and to place it within 2) a broader worldview and 3) network of commitments, occur over an extended period of time (Kuhn, 2012). These activities constitute the underlying structure of scientific revolution, reflected in the construct, metaphysical and sociological senses of paradigm.

Masterman's three senses of paradigm provide a much needed, if underappreciated,[18] clarification of Kuhn's central concept and the sequential steps of a scientific revolution. Once established as "an actual artefact [that can be] used analogically" (Masterman, 1970), a construct paradigm may be extended through primitive puzzle-solving to establish a comprehensive worldview (i.e., metaphysical paradigm) and, through further refinements and debates of theory choice, to formalize the shared network of methodological, theoretical, and instrumental commitments (i.e., sociological paradigm) that support the refined puzzle-solving efforts and continued progress of a scientific community.

Although the ontological and epistemological aspects of early-stage or crisis-driven investigations are intertwined in complex ways,[19] the work of Kuhn and Masterman suggests that the dual nature and dual function of a construct paradigm can be revealed through historiographic case studies of actual scientific practice. By using a practice-based approach to identify the primacy of a construct paradigm, we gain greater insight into the processes and authority for moving from a primitive puzzle-solving construct to a comprehensive worldview and a shared network of commitments. In the context of our investigation, we gain insight into the methodological processes and epistemological authority for changing mental models and improving strategic decision-making.

5. Implications of the three senses of paradigm for scenario methodology

In applying the three senses of paradigm to scenario methodology, we here translate into plain language Masterman's academic classifications (i.e., construct, metaphysical, and sociological senses of paradigm), as construct paradigm, worldview paradigm, and action paradigm. These refined conceptions remain true to the content and spirit of Masterman's classifications while providing a more straightforward indication of the role, contributions, and distinctions of the three senses.

5.1. A preliminary framework for scenario methodology

The three senses of paradigm represent three achievements, which align with the objectives identified by Wright et al. (2013) and the activities conducted by Wack (1985a). Like a Rosetta Stone integrating the dimensions and processes of changing, the combination of these three areas of research provides a translational framework for understanding the objectives, activities, and achievements of exploratory, reframing, and decision scenarios (Table 4). They outline a path for using scenarios to improve decision-making in situations of discontinuity.

As outlined above, exploratory scenarios enhance understanding by structuring uncertainties, exploring their interplay, and identifying predetermined elements. The outcome of these efforts is a (new or refined) ontological-epistemological construct (i.e., construct paradigm) that serves both to define (ontologically) and to guide (epistemologically) explorations of how the uncertainties develop over time. At Shell,

[16] This question is similar to Burt's (2007) question regarding the use of scenarios in situations of discontinuity, i.e., how can scenarios "affect decision-makers' view of reality?"

[17] The dual nature of a construct paradigm suggests it is a special kind of analogy, possessing both A- and B-concreteness as an "actual artefact used analogically" (Masterman, 1970).

[18] Discussions of Masterman's (1970) work often focus on her identification of Kuhn's 21 uses of the term paradigm, without addressing the three senses of paradigm or the primacy of a construct paradigm (Hacking, 2012). Even Kuhn failed to appreciate her contribution, conflating the construct and metaphysical senses of paradigm in his refined conception of paradigm as an exemplar (Kuhn, 1970). In his later investigations of exemplars as metaphors, Kuhn distinguishes constitutive metaphors (i.e., construct paradigms) from "merely exegetical" metaphors (i.e., metaphysical paradigms) but makes no reference to Masterman (Kuhn, 1979). Nickles (2000) provides an insightful exploration of exemplars and "Kuhn's acquired similarity-relationship … as the primary schema structure or process."

[19] Important philosophical considerations and implications of this proposal are outside the scope of this paper, for example, the relationship between ontology and epistemology in linguistics, cognitive science (Nickles, 2000) and data science (Anderson, 2008; West, 2013).

Table 4
Objectives, activities, and achievements of exploratory, reframing, and decision scenarios.

Objectives of effective IL scenarios ("what") Wright et al. (2013)	Activities of IL scenarios ("how") Wack (1985a)	Achievements of IL scenarios ("to what effect") Masterman (1970), adapted.
1. Enhancing understanding: • of the causal processes, connections, and logical sequences underlying events; • thus uncovering how a future state of the world may unfold.	1. Structure the uncertainties (1970/1971 "exploratory" scenarios): • explore the interplay of uncertainties; • identify predetermined elements.	1. Construct paradigm: • a generating analogy that functions as an ontological-epistemological construct of the uncertainty its development over time; a basis for primitive puzzle-solving (i.e., when the theory isn't there).
2. Challenging conventional thinking: • reframe perceptions; • change the mindsets of those within organizations.	2. Provide a basis for judgment (1972 "reframing" scenarios): • outline potential changes in macrocosm (i.e., real world); • develop executives' understanding of the nature of uncertainties and help them come to grips with them.	2. World view paradigm: • a comprehensive and internally consistent view of reality, including the interplay of factors and their development over time; • a resolution of issues of incommensurability and debates of theory choice.
3. Improving decision-making: • inform strategy development.	3. Support changes in the mental models of decision-makers (1973 "decision" scenarios, The Rapids): • change the microcosms of managers and the organization; • help managers reconstruct their mental models; • use scenarios to build a bridge to decisions and actions.	3. Action paradigm: • a comprehensive account of a community's habits or ways of working, guided by its ways of seeing, translated into action; • applications of theory by means of a community's shared network of methodological, theoretical, and instrumental commitments.

the 1970 and 1971 exploratory scenarios analyzed and confirmed the potential for discontinuity through their initial accounts (i.e., construct paradigm) of how the discontinuity might develop and how key players might respond.

Reframing scenarios challenge conventional thinking by developing a new or refined basis for judgment, that is, a worldview paradigm. By analyzing uncertainties and shared views of the macrocosm, they challenge conventional thinking, reframe the perceptions of decision-makers, and help them come to grips with the change. At Shell, the 1972 reframing scenarios overturned managers' business-as-usual worldview by convincing them the discontinuity could not be avoided and forcing them to face the magnitude of industry disruption.

Decision scenarios improve decision-making by supporting changes in the mental models of decision-makers and establishing a paradigm for action. By linking new (or refined) ways of seeing to managers' deepest concerns, decision scenarios support new (or refined) ways of working. The 1973 decision scenarios at Shell (The Rapids) compelled managers across the company to develop a new action paradigm by connecting the reality of discontinuity (i.e., macrocosm) with the microcosm of managers across the organization.

5.2. A systematic approach for using scenarios to change mental models

On the basis of Kuhn's framework for scientific revolutions, we can reexamine the activities used to develop the Shell scenarios as the basis of a systematic approach for using scenarios to change mental models and improve decision-making in situations of discontinuity.[20]

The steps outlined below are presented according to the same numbering system as our exploration of Kuhn's new image of science (i.e., 3.2.1 through 3.2.7). Previous descriptions of Kuhn's theory are adapted to reflect the activities of the Shell scenarios and generalized to support a systematic approach.

5.2.1. Strategic decision-making entails a series of puzzle-solving activities

The strategic decision-making that results from both analytic and developmental approaches to strategy corresponds to the puzzle-solving activities of science. Although there are clear differences in the subject matter, methods, criteria, and authority of the approaches, they share the nature and focus of puzzle-solving.

The evolution of planning processes at Shell can be understood as an ongoing series of puzzle-solving activities, with each change in planning reflecting a response to perceived or anticipated changes in the business environment (see again Table 1). Each new approach to planning gained prominence over the previous one by providing a clearer resolution of the current issues facing the organization.

5.2.2. Explorations of uncertainties include investigations of anomalous observations that emerge from puzzle-solving activities

Anomalous observations represent a special type of uncertainty that arises in the normal course of planning activities. In some cases, they may present a direct challenge to established practices.

At Shell, the potential for a major discontinuity in oil markets represented an anomaly that challenged the organization's strategy and planning processes. The group's operations and organization were optimized for market dynamics that had predominated since World War II, and managers' judgment was finely attuned to the resulting challenges and opportunities. The potential for discontinuity threatened the group's competitive position, establishing the need for further investigation.

5.2.3. Scenario-based explorations reflect a shift from puzzle-solving to boundary-testing, that is, from "normal" to "extraordinary" investigations

As a tool for exploring uncertainties and plausible futures, scenarios expand strategic perspectives. Although scenarios can be used to support or enhance the puzzle-solving activities of "normal" investigations, their unique value lies in the "extraordinary" task of looking beyond and testing established boundaries. As such, they are uniquely suited to investigations of potential discontinuity.

In the face of a discontinuous shift in oil markets, the highly structured and detailed nature of Shell's UPM was a limitation, rather than strength. Designed for a market dominated by buyers, its forecasts could not be translated easily to competing based on supplier power. Although UPM remained the primary planning vehicle for Shell until 1973, the activities of Pierre Wack's scenario planning group reflected "extraordinary" explorations of the prospects and paths of discontinuity.

[20] The three senses of paradigm also reflect different types of causality and criteria for assessment, e.g., Derbyshire and Wright, 2017. Examination of these differences will refine our systematic approach even further.

5.2.4. Exploratory scenarios structure uncertainties

Exploratory scenarios are designed to analyze uncertainties, give them structure, and explore their interplay in order to identify predetermined elements. By looking beyond a business-as-usual perspective, exploratory scenarios reveal emerging cracks in established (ontological-epistemological) constructs and identify potential resolutions.

The 1970 Horizon scenarios confirmed predictions of market discontinuity, raised questions about the continued validity of UPM planning processes and showed scenarios to be a valuable tool for understanding the coming changes. In designing the 1971 exploratory scenarios, Wack's team worked like scientists trying to "isolate an anomaly" and "give it structure."

Yet structuring an anomaly, or even resolving it, is not enough. The success of both Shell's planners and Kuhn's scientists depends upon providing a basis for others to exercise their judgment. For scientists, this is the broader community of scientists within their field. For planners, it is the decision-makers and middle managers who design and implement the strategy. Particularly in situations involving substantial changes in the network of commitments, investigations and presentations must be designed to respond to the deepest concerns of these broader audiences.

5.2.5. Reframing scenarios provide a (new) basis for judgment but raise the challenge of incommensurability

Once the structure of uncertainties (or a potential discontinuity) is established, reframing scenarios provide a basis for judgment, that is, a way of seeing the (new) world. In doing so, they place the uncertainties within the context of a broader worldview or view of reality (i.e., Wack's macrocosm). Any changes to this worldview must be developed and justified as preferable to established perspectives. Investigations must address the issues of incommensurability and debates of theory choice.

In the 1972 reframing scenarios, Pierre Wack challenged the business-as-usual mindset directly. Senior executives became convinced the discontinuity was predetermined, yet internal presentations failed to convince middle managers. Given the fundamental nature of the challenges to established ways of working, additional work was needed to convince middle management and to help them identify appropriate actions.

5.2.6. Decision scenarios compel managers to change their mental models of reality by building a bridge from the new reality to managers' deepest concerns

Decision scenarios help decision-makers use their new ways of seeing to develop new ways of working. The goal is to compel action by linking the new realities to the deepest concerns of decision-makers.

In designing the 1973 scenarios, Wack and his team changed their objective and approach from developing "good" scenarios to changing the mental models of decision-makers across the Shell organization. Based on the findings of the earlier scenarios, "The Rapids" established discontinuity as the surprise-free scenario. Detailed strategic and operational analyses helped managers to restructure their mental models in ways that would compel action. Through direct warnings about the character of the new environment, Wack and his team built a bridge to managers' deepest concerns.

5.2.7. The use of scenarios to change mental models provides both a response to crisis and a path for discovery

Situations of discontinuity provoke a crisis by undercutting decision-makers' greatest source of strength: alignment of their judgment with the realities of their business. To realign managerial judgment, changes in mental models adjust the microcosm of individuals across an organization to reflect the new realities of the emerging macrocosm. Scenarios offer a uniquely valuable approach to seeing this new world and changing the way managers work within it.

At the heart of these efforts is "the gentle art of re-perceiving" (Wack, 1984). Planners and managers who are able to see and adapt to the new realities can establish a position for their company more quickly and more completely than competitors. As Pierre Wack explains, "[i]t is precisely in these contexts – not in stable times – that the real opportunities lie to gain competitive advantage through strategy. 'Uncertainty my friend…discontinuity *mon amour*!'" (Wack, 1984).

6. Conclusion and areas for further research

This article explores the approaches, challenges, and opportunities of using scenarios to change mental models and improve strategic decision-making in situations of discontinuity. Much like Kuhn's new image of science, it is a schematic account, informed by real-world experience and enriched by research in related fields. It reveals both the power and the limits of analytic and developmental approaches, suggesting a refined image of strategic decision-making as a series of analytic achievements and developmental investigations, punctuated by rare but revolutionary breaks and discontinuities. In these situations – when established (analytic and developmental) tools and frameworks fall short – scenario methodology plays a crucial role in exploring the discontinuity, reframing decision-makers' mental models, and re-establishing a sound basis for decision-making.

As with Kuhn's account, more remains to be done, including additional case studies, further refinement of the theoretical framework, and investigation of the following questions:

How (and by whom) are discontinuities identified? Kuhn's account suggests that anomalies emerge in the course of puzzle-solving. In the case of Shell, the discontinuity was identified by the Year 2000 study. Is there a systematic way to identify potential discontinuities? What are the processes for linking this identification with the use of scenario methodology as the appropriate tool for further analysis?

What analogies, frameworks or models can be used to identify and to structure emerging discontinuities? Wack emphasizes the importance of design in developing scenarios, and Kuhn notes that the processes used to isolate an anomaly and to give it structure are consequential for how the anomaly is resolved. In the case of Shell, the predicted shift in oil markets provided not only the motivation but also the direction and structure for investigations. For managers, emerging discontinuities such as shifts in industry structure, business models, technologies, etc. can be identified and assessed using established frameworks or models, such as Five Forces (Porter, 1980), the Value Chain (Porter, 1985; Vecchiato and Roveda, 2010), or Disruptive Innovation (Bower and Christensen, 1995). Additional examples and detailed case studies would help in identifying potential discontinuities and linking them with managers' deepest concerns.

What discontinuities are emerging now in macro- and market environments? Although discontinuities are usually rare (particularly for established companies), over the past few decades, globalization and technology development have prompted discontinuous shifts across many industries, with consequential (and cascading) effects. The recent global rise of nationalism and populism, impending effects of automation on job growth, generational shifts, and threats of climate change represent important potential developments that are likely to create disruptions or even discontinuities for private, public, and non-profit organizations and individuals around the world. How can researchers identify these potential shifts at an early stage, in order to help decision-makers face and navigate the changes and transitions ahead?

What analyses can be conducted (by whom, and with what criteria) to support the use of scenarios in moving across the three senses of paradigm? Investigations by Kuhn and Wack provide initial suggestions (Table 4), however, further case studies, research, and guidelines are needed [e.g., Chermack, 2007; Derbyshire and Wright, 2017]. Research in sense-making (Weick, 1995), managerial cognition (Gavetti et al., 2005) and the case method[21] are helpful sources of guidance.

How can scenario methodology address the problem of

[21] For example, similar activity-based or case-based approaches are used to develop theories (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Nickles, 2000; Yin, 2003) and to build or to strengthen managerial judgment (Barnes, Christensen, and Hansen, 1975–1994; Christensen et al., 1991 and Garvin, 2003).

incommensurability? Changing the mental models of decision-makers requires addressing the incommensurability of old and new mental models as well as philosophical issues of theory choice. This is the primary challenge of reframing and decision scenarios: how to convince managers across the organization to abandon old ways of seeing or working and to develop new ones? As a starting point, both Kuhn and Wack outline some of the activities involved (Table 4).

What are the factors (beyond scenarios) that provide the "vital bridge" between scenarios and strategy? While scenarios can be designed and presented in ways that help managers restructure their mental models, researchers are exploring a number of factors influencing managerial cognition (Tripsas and Gavetti, 2000, Gavetti et al., 2005. By understanding the full range of influences, we can improve scenario design, methodology, and analysis.

How can improvements in scenario methodology benefit research in strategy and other fields? The challenges presented by discontinuities are evident in both scenario methodology and strategy. If we can develop more systematic approaches for using scenarios to change the mental models of decision-makers, the benefits of those approaches and their achievements can accrue to both fields.

In addition to these specific questions, it is important to build on and to incorporate this work within the research literature of scenario methodology and related areas. These include, but are not limited to sense-making, decision-making under uncertainty, disruptive innovation, managerial cognition, cognitive science, and related developments in linguistics, ontology, and epistemology.

6.1. Concluding thoughts

In Chapter VI of *The Prince*, Niccolo Machiavelli advises, "It ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in outcome than to take the lead in introducing a new order of things." Thomas S. Kuhn's account of scientific revolutions provides a rough sketch of the underlying structure of such an undertaking, and the controversies surrounding his work serve as an illustration of the difficulties, perils, and uncertainties that arise.

In the context of strategic decision-making, the challenges of discontinuity (both for leaders and for their organizations) set a high bar for success. Whether encountered as disruptive innovation or industry crisis, situations of discontinuity present substantial opportunities and risks, with few, if any, guidelines. In these cases, scenario methodology provides a way to explore potential discontinuities, reframe established worldviews, and change mental models in order to (re-)align managerial and corporate judgment with the emerging realities of the changing world. This recognition and realignment are critical to effective, strategic decision-making. In situations of discontinuity, scenario methodology thus not only improves decision-making to inform strategy, it makes it possible once again.

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