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KIC4: A Four-Dimensional Model for Industrial Symbiosis: Validation with Key Stakeholders

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Abstract

The traditional definitions of Industrial Symbiosis broadly describe it as a symbiotic relationship between enterprises usually operating in close geographic proximity within an industrial precinct where the reduction of waste and by-products through re-use of these materials is the goal, and is more recently described within the broader construct of Circular Economy. But there is more to a successful industrial precinct than simply the business-to-business relationships associated with these by-product material exchanges. The literature is slowly beginning to explore the presence of various forces that also have a role to play. The novelty of this research is that these forces have been explicitly identified as being a mix of four relationship-based synergies. These were identified and crystallized through a series of four sequential papers, and provisionally grouped under four headings, or dimensions; Materials Exchange, Skilled Workforce, Support Industry, and Governance. The purpose of the research was to develop a model which could be used to create a dimensional profile for any given industrial precinct. For each of these dimensions, a set of five influencing factors were identified, and collectively they were used to build a profile for a given industrial precinct. Analysis of the dimensional influencing factors was expected to deliver insights into the extent to which they may or may not be impacting the performance of the enterprise actors located within it. Respondents from four distinct groups associated with the precincts (policy makers, precinct managers, enterprise managers and representative groups) were selected for the research and were asked to characterise their precincts by rating each set of dimensional influencing factors. The major finding of the research was that the reason for the relative strength or weakness of an industrial precinct can be described under this four-dimensional framework which has been called the KIC4 Model of

Industrial Symbiosis. The evidence after testing these influencing factors in various state, national and international greenfield and brownfield precincts confirmed that the data obtained showed the interrelationships and can be used to enhance the design or re-design of complex industrial precincts to equip the existing enterprises and those considering locating within them, to achieve higher levels of circularity and production efficiency.

Keywords

Industrial Symbiosis, Kwinana Industrial Area, Kalundborg Industrial Area, KIC4, Four-Dimensional Model, Circular Economy

1. Introduction

1.1. Context of the Paper

This paper is the fifth in a series of papers for a thesis by compilation. The primary research question for the thesis is: *Can a decision support framework be developed so that when it is applied to a given industrial precinct, it rates the extent to which the precinct can be conducive to the operation of the enterprises located within it?*

The research questions asked in the first paper (Oughton et al., 2021) are summarised as: *Are there indications of symbiotic relationships that lie beyond the traditional definition of industrial symbiosis, the symbiotic relationship between two enterprises where by-products of one become an input of the other?* Two industrial process water case examinations focused on the Kwinana Industrial Area (KIA) in Perth, Western Australia (WA). These were selected to explore what influencing forces were impacting project outcomes. In identifying four forces, the case examinations indicated that if one or more of these were absent or dysfunctional in the industrial precinct, the opportunity for a well-functioning Circular Economy (CE) was diminished. The conclusion made in this paper was that the traditional view of Industrial Symbiosis (IS) presents an individual dimension of a broader framework of interconnected systems. The literature reviewed did not contemplate this view and consequently it was posited that IS did appear to be comprised of four distinct dimensions.

The second paper was a comprehensive review of the literature associated with industrial symbiosis and the extent of its expansion into areas beyond the traditional materials exchange paradigm (Oughton et al., 2022). It addressed the core question: *To what extent researchers have moved beyond the traditional view of Industrial Symbiosis, where it is singularly focused on the symbiotic product, by-product and utility materials exchange relationships?* It attempted to identify other forms of symbiotic relationships that might also contribute to the improved economic outcomes of enterprises located within complex industrial precincts. The review concluded that while there has been little targeted investigation into the existence of factors other than traditional IS that might explain

why some industrial areas are more successful than others, the emergence of four dimensions of IS was none-the-less documented.

The research question asked in the third paper was: *Through an expansion of the posited Governance Dimension of IS, what influence does this have on the functioning of an industrial precinct?* It was a comprehensive review of the literature associated with the governance dimension of the posited four-dimensional framework, and was supplemented with a practical demonstration of how the cascading climate change policy framework (from global through to local) was applied to a major industrial precinct (Kwinana) despite a lack of policy leadership from some important policy actors (Oughton et al., 2023a).

The research question asked in the fourth paper was: *What are the most important characteristics of an industrial precinct and how might they be grouped?* The objective of this paper was to test for the presence of the posited four dimensions to provide insights into what role they play in explaining why some industrial clusters appear to provide a supportive business environment, and why other clusters struggle to achieve momentum (Oughton et al., 2023b). The Kwinana precinct was used as the data source for characteristics in relation to the skilled workforce that services it, any support industry base, and its overarching governance framework. It concluded the redefinition of traditional IS into four dimensions appears to be valid and that further research was warranted. It suggested that the posited four-dimensional framework (KIC4) be developed into a tool to be applied to create a dimensional profile for any given industrial precinct multipurpose model so that it can be used to deliver a mix of outcomes.

1.2. Literature Review

Over the years, scholars have observed the broadening of the IS concept. In 2000, Chertow advanced the definition of IS by adopting the approach that as a minimum IS needs to be at least three independent enterprises engaged in the exchange of more than two materials (Chertow, 2000). Chertow referred to this as the 3 - 2 heuristic model, extending the reference to IS beyond a simple relationship where a material is exchanged between two enterprises, to multiple exchanges within complex relationships. Next, Jensen raised the importance of geospatial industry diversity, referring to a range of different enterprises located in one larger geographic precinct being a necessary element for IS to develop strongly (Jensen et al., 2011). Soon after this, Lombardi introduced aspects of enterprise eco-innovation, and its association with enterprise culture change (Lombardi & Laybourn, 2012). They saw this emerging thought as leading to other less definable aspects of IS, and broadening the world view of IS perhaps into aspects not yet considered. Their definition of IS referred to diverse organisations individually, or an entire industrial precinct, where the presence of commercial by-product stand-alone transactions is characteristic, and where the exchange of inputs and outputs are agreed between a sender and receiver to improve business outcomes. Velenturf further discussed the benefits of geoprox-

imity and geospatial diversity, where IS itself fosters eco-innovation and long-term culture change, in addition to the sharing of knowledge within the network to yield mutually profitable transactions for the novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes (Velenturf & Jensen, 2016). Luciano made reference to the diversity of enterprises as part of the creation of IS benefits in addition to the usual materials exchanges (Luciano et al., 2016). In leading the reader to consider what else is therefore needed to improve business sustainability, he referred to the required skill sets of the workers, and other additional benefits of IS that are found beyond traditional IS material exchange, concluding that something else beyond the mere existence of opportunity leads to improved enterprise competitiveness. Key elements in this definition tend to link Jensen's geospatial diversity to Chertow's materials reuse to enhance cost competitiveness. Others have developed a range of models that look further than the basic exchange of materials. Kurup's "Six Capitals" model explores the broader economic, social and environmental impacts of these IS exchanges, leading to the observation that the traditional headline field of IS has of itself expanded in its scope, indicating a deepening understanding of its value and benefit (Kurup, 2007). Another model, proposed in a study into one of Australia's heavy industrial areas, Gladstone, focused on the development of an IS "Maturity Grid" (Golev et al., 2015). His work broadened the traditional conceptuaisation of IS into areas that go beyond materials exchange toward regulation, trust, and economic barriers. In their recently published paper Chakraborty investigated the enablers and barriers associated with CE focusing on the Australian SME sector (Chakraborty et al., 2023). The findings pointed to the pressing need for public sector governance to provide clear, sectorial, political leadership to aid in the acquisition of new technologies. Lewis wrote in reference to indusrial clusters, where industrially themed sectors were producing similar products and operating within traditinal industrial areas (Lewis et al., 2023). Barbieri identified that where enterprises were looking toward externalities for operatinal improvement, they could utilise the precinct's common-user infrastructure and work collectively to reduce costs and improve productivity (Barbieri et al., 2012). They referred also to, in their case, the UK government making commitments to assist and even enable the progression of industrial precincts towards green hydrogen prodiction and industrial decarbonisation. They concluded there can be a positive relationship between an industrial cluster and the localities within which their workers reside, even in times of sustainability transitions such as decarboinsaion. Continuing on the deacrbonisation theme, Lu concluded that different precinct locations generate a connection with the respective workforces (local community) and that they respond differently to negative distruption (Lu et al., 2022). The energy transition therefore needs to bring the local people (workforce and community) along on the journey, thus identifying a relationship between industry and its local workforce. Edwards wrote about the relationships required in order to transition in-

dustrial precincts towards more sustainable outcomes, in that instance, hydrogen outcomes (Edwards et al., 2022). Much focus went on to the roles of various sectorial stakeholders including governmental policy makers, industry and enterprises where they identified situations where actors found it difficult to achieve a common voice. They extended the work of Enhert where partnerships between sectors and domains were exibiting dysfunction, and whilst further confirming this, also found that the dysfunction was especially occurring within the public sector (Ehnert et al., 2018). In essence, they had found that the poor quality of the governance sector relationships were providing challenges to industry through uncertainty around a lack of supporting policies and the funding opportunities to encourage sustainability transitions. The relationship between the governance sector and industry was problematic for the industrial actors.

In documenting several aspects of this evolutionary expansion of IS, Oughton's literature review concluded that a given industrial area's environment includes a range of influencing factors (IFs) in addition to those associated with the traditional Materials Exchange; these being able to be grouped under the posited dimensional headings of Skilled Workforce, Support Industries and Governance (Oughton et al., 2022).

In their paper, Boons discussed the difficulty associated with finding concepts related to IS that identified equivalent empirical phenomena in the international context, thus exposing the lack of common understanding about IS and the difficulty in comparative analysis between industrial precincts (Boons et al., 2017). The nature of such analysis (for wide application) was postulated through their presentation of seven dynamics associated with IS, with each being characterised by the actors, their motivations and the outcomes. In their paper they suggest that there needs to be further research into deepening the understanding of IS in its "vastly different manifestations", and "the dimensions for which they (future researchers) look for commonalities and differences in the cases (industrial precincts) they are comparing". In concluding they presented the challenge to improve the links between economic and environmental performance in a broad array of circumstances.

In the industrial setting, IS is being increasingly discussed as a framework to continue the transition of enterprises from internally focused economic improvement practices to those which are more interconnected with the activities of enterprises ranging from a precinct setting to the broader social and economic sustainability scale of an economy (Dey et al., 2020). Latterly, CE is viewed as the organic emergence of sustainable development framework practices over 40 years, including IS in the 1990s (Neves et al., 2019). The application of CE principles in the industrial setting relies on the building of sustainability principles focused toward the micro-level, and translating to CE activities at the macro-economic level (Oughton et al., 2022). A CE framework presents the situation that at the macro-level there is a closed-loop flow of materials, in other words, everything is an input to everything else (Su et al., 2013). Clearly, this concept is broad, encapsu-

lating many things, and there appears to be little definitive agreement on what its components are (Rizos et al., 2017). Given its evolutionary origins, perhaps this is quite reasonable because CE is postulated to be a journey to a more advanced conceptual framework, described as Replenishment Economy (Oughton et al., 2022). Perhaps attesting to the broad conceptualization of CE is the application of descriptive cliches such as "closing the loop" (Nancy et al., 2017), "umbrella concept" and "reduce the knowledge gap" (Merli & Acampora, 2018).

Internationally, research on CE is evolving rapidly (Centobelli et al., 2020). Much of this research focuses on either the larger industrial organisations and their dealing with waste, or aspects of the associated supply chains for improved cycle efficiencies (Govindan & Hasanagic, 2018). Australian enterprises have a growing awareness of CE, and view progress toward its principles as being increasingly central to their economic sustainability (Sohal & De Vass, 2022). Emerging from academia are new quantitative models designed to measure different aspects of industry, from individual enterprises or scaling up more broadly to be applied to precinct-based collectives. One such model produces an index which is a measurement of the extent to which three sustainability goals (social, economic and environmental) as they relate to enterprises and their products, are impacted by IS (Pandey & Prakash, 2019). As described earlier, IS and its foundation in relationships has been evolving in the industrial setting for decades. This work is yet another expansion of contemporary IS and can be aligned primarily within governance dimension of the KIC4 model for IS.

In Australia, management of major industrial precincts is commonly a governmental function (Development WA, 2022, 2023a, 2023b, Queensland Government, 2023). The manager, in being aware of possible constraining aspects of the common user infrastructure it provides, and for whatever reason, may not make the required investments needed to improve those characteristics of its precincts required to assist the enterprises located within with their drive toward international competitiveness. Making this investment may just simply not be a priority for a government. However, in Australia, several State-based governments have incorporated CE principles and policy requirements into their precinct planning and management to address this (Halog et al., 2021). But it is not governments alone that are driving this journey towards CE, so too are industry sectors, and the WA resource sector is a good example of this (ASBFEO, 2019). A cooperative approach between enterprises within a sector, often in association with an industry association, is making strong advances through the development of strategies to deliver more skilled workers into their sectors and to establish collectively based decarbonisation strategies ((Kwinana Industries Council, 2021), https://kic.org.au/, 2023).

2. Motivation for the Research

2.1. Motivation

The motivation for this research was to progress the idea of an applied tool being used for the evaluation of industrial precincts, and to test this through a formal

research process such as a stakeholder survey and interview. This included the development of a range of IFs for each dimension that have a collective influence on the potential for an enterprise's commercial sustainability. For example, a factor could be the presence of constrained common user infrastructure (berth availability at a freight port wharf), which in this condition is likely to not only increase costs of production through decreased productivity or delayed raw materials delivery, but can also make the precinct an unattractive destination for further industrial investment. In relation to the enterprises located within a precinct, there are numerous barriers to the development of strategy around environmental and capacity improvement, problematic governmental policy expansion leading to unwanted interference or even market distortion (Oughton et al., 2023b). There was an inability to identify an applied tool that could be used to assess the extent to which a precinct could provide an environment in which the resident enterprises could be supported. During the preparation for this research, the KIC4 tool (**Figure 1**) was built and it proceeded to being tested against several Australian precincts as well as the highly regarded Danish precinct at Kalundborg. In the LiSET (Lifecycle Screening of Emerging Technologies) model, a "traffic light" colour graded approach was applied to providing a matrix structure to present a progression of technological development (Hung et al., 2020). The essence of the model is that the four dimensions of IS, the subject matter of this paper, are assessed for their strength for a given industrial precinct. The strength of the precinct per dimension is presented as a quartile rating which is expressed through the intensity of the colour allocated to each dimension. The strongest colour in the gradient means it has been rated by respondents as quartile four, and the weakest colour in the gradient means it has been rated at quartile one. The research underpinning this paper focused on the assessment of several industrial precincts, and for interpretative purposes, the pictorial profiling of each for easy comparison.

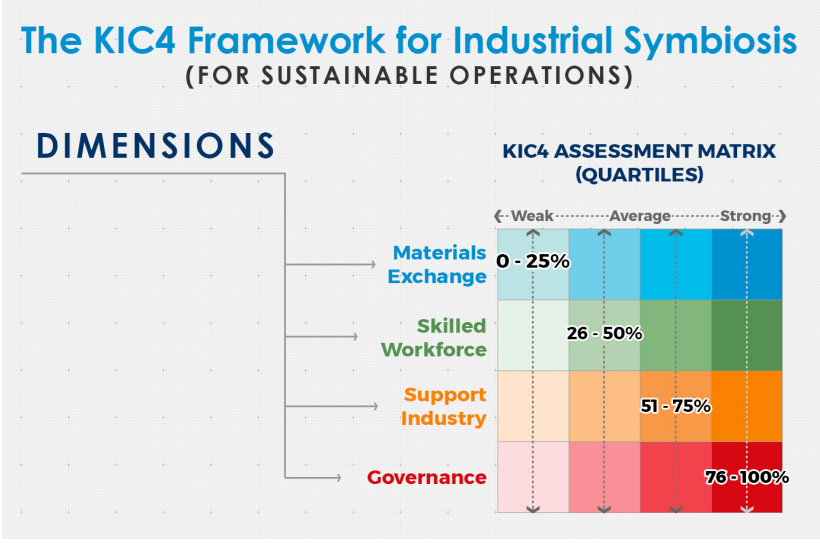


Figure 1. The KIC4 framework.

This approach was applied to the presentation of the KIC4 data by firstly colour coding (hexcode) each of the four dimensions separately, and then for each dimension using a colour intensity gradient (Figure 2), or heat map, to reflect the quartile rating of scores for each dimension as a quartile rating.

2.2. Research Questions and Purpose of the Paper

The core objective of this paper was to further develop and test a standardised KIC4 framework to be applied to developing a four-dimensional profile for any given industrial precinct. Development included formalising the five key IFs per dimension and via a survey instrument, to gather quantitative data to enable a dimensional profile to be built. Qualitative data was also gathered from respondents to identify qualifying commentary and suggestions for improvement. Respondents from a total of nine discrete industrial precincts were surveyed to test the effectiveness of the model.

The purpose of this paper then, was to test to what extent the symbiotic dimensions of a precinct, each supported by a series of IFs, impact on its ability to facilitate the advancement towards CE outcomes for its resident enterprises, and to provide an environment for facilitating strong commercial sustainability. This purpose raised two primary research questions: What are the influencing factors that support each dimension of the KIC4 model, and does the KIC4 model provide a reliable process by which it can be replicated to deliver accurate dimensional precinct profiles?

3. Methods

The earlier Oughton paper was instrumental in gathering respondent data that would subsequently be refined and used for the formation of the series of IFs for each of the four dimensions (Materials Exchange, Skilled Workforce, Support Industries, and Governance) (Oughton et al., 2023b). In response to the research questions, an extensive list of IFs that could affect the performance of any given industrial precinct was developed.

The research method used for the development of this paper is of the comprehensive type. The accumulation of evidence and its synthesis into a comprehensive set of factors broadly followed the eight-step standardised qualitative

KIC4 Dimensional color palette

	Q1	Q2	Q3	Q4
D1	#bce4e6	#6fceea	#01bdea	#0091d0
D2	#e6f2e8	#b5d2b3	#82b87c	#559151
D3	#fee4cb	#fcbe85	#f89947	#f98200
D4	#fcdcdf	#f89195	#f2424c	#d60812

Figure 2. Dimensional colour palette specification (Microsoft Inc.).

methodology (Okoli, 2015). Rousseau posits that research can be a "comprehensive accumulation, transparent analysis, and reflective interpretation of all empirical data pertinent to a specific question" (Rousseau et al., 2018). The comprehensive research was used to synthesise, assemble, analyse, and importantly to interpret evidence gathered in a highly reflective fashion. An additional category of literature review is referred to as "standalone" which Fink writes is distinguished by its scope and rigor leading it to become a reference point or a clear outline of the literature for researchers undertaking a new investigation (Fink, 2005). This standalone review summarises the existing evidence, identifies gaps in current research, and provides a framework for positioning future research endeavours. Reviews of this type are valuable in informing policy and supporting practice (Petticrew & Roberts, 2007). A practical interpretation of the KIC4 model's application is provided by making observations about certain precincts.

The survey instrument was developed to gather data about the dimensional IFs to identify those attributes that were found to be contributing to enhanced circularity, or to a precinct's strengths or weaknesses. Thirteen precincts were selected for the research. Six were identified from WA for a number of reasons; these being that authors were more familiar with their characteristic (for data verification purposes), that they wanted a WA state-based cross-section of precincts displaying a broad range of attributes, and the identification/interviewing of suitable respondents was made more efficient. All of these participated in the survey. Four well known precincts were selected from other States within Australia, with two agreeing to participate (Gladstone and Port Kembla). A further three well-credentialled precincts from international jurisdictions were identified (Humber, Rotterdam, and Kalundborg), with the latter agreeing to participate. Within the thirteen precincts selected, two internationally well-regarded industrial precincts were identified to be invited to participate in the research. Both of these, Kalundborg (Denmark) and Kwinana (Australia), agreed to participate. Kalundborg was selected because in Europe, this precinct has the well-earned reputation for being the best example of IS, and numerous scholarly papers attesting to this have been published over many years recognising is virtues as the long-recognised standout example of IS (Ehrenfeld & Gertler, 1997; Ehrenfeld & Chertow, 2002; Jacobsen, 2008; Orsted, 2017; Kalundborg Symbiosis, 2023). To prove the model's efficacy, the data generated through the application of the KIC4 tool would need to reflect the documented strength of the precinct across the four dimensions. Kwinana was similarly selected because of its international recognition and scholarly prominence, and also for its recognition by the WA Government as being the State's Premier Industrial Area (Oughton et al., 2023b; Golev et al., 2015; Kurup et al., 2005; van Beers, 2006; van Berkel, 2006; Harris, 2008; van Beers et al., 2007; Kurup & Stehlik, 2009). Kwinana is WA's premier strategic industrial area and is situated within the larger precinct referred to as the Western Trade Coast, located some 40 kilometres south of the Perth Central Business District (Oughton et al., 2022; Sinclair Knight Merz &

Resource Economic Unit, 2014).

The purpose of the survey was to collect data set from a range of industrial precincts exhibiting differing attributes to enable a diversity of comparative dimensional profiles to be developed and presented. Characteristically the selected precincts needed to include some that are perceived as performing well for their resident enterprises, some that are regarded as poorly performing, and some "iconic" precincts that have been the subject of substantial academic research over several years for comparative purposes. To fulfill the dataset requirements of the model, quantitative data about the key characteristics of each of the selected precincts was required, including; distance to nearest major population centre, presence of direct access to a port facility, the physical area (ha) and expansion potential, the actor fulfilling the "owner/manager" role, year of establishment, and if the precinct was progressing as a collective to a "net-zero carbon" outcome. The survey instrument further interrogated respondents to determine their qualitative views about what were the most important IFs per dimension to build a strong and vibrant precinct. An open question seeking any further comment was also asked. The space (precinct area and land available for expansion) and time (age of the precinct) characteristics of the precincts were considered to be important in the context of the maturity of IS being a major factor in the industrial ecology of the place. It was considered important to test the extent of the influence, if any, of the organic nature of an industrial precinct on its ability to be conducive to business in other words, was the precinct a product of an industrial ecology that had grown over time to maturity?

To provide for future granular analysis of the data, four actor groups per precinct were identified, each having a different role and (presumably) perspective associated with their given precincts.

Group (G) 1: Federal (or National) government representatives provide a national strategic and policy perspective.

Group (G) 2: State government representatives (where applicable), hold a strategic perspective, but also because in Australia it is through this actor group that the management, regulation, and provision of collectively available common user infrastructure is delivered.

Group (G) 3: Industry association presidents/CEOs, provide an ability to draw together the issues affecting their members and to present the overarching, and collective view of the precinct's enterprise managers.

Group (G) 4: Industry enterprise senior management relevant to the selected precinct. These actors are at the coal face of the realities of dealing with the issues that go straight to the ability of an enterprise to achieve necessary levels of financial and production efficiency. Collectively they effect change through their industry association, if available, and/or through their corporate affairs activities.

For the purposes of practicality, clarity of question, and the production of quality data, the draft instrument was validated by testing it with two potential survey respondents from industry, one from each of groups 1 and 2, and a fur-

ther two from amongst the authors of this paper. Following review, adjustments to the instrument in the form of clarifications and additional information were then incorporated into the final version. Research to identify the actual respondents per selected precinct was completed by contacting known actors and seeking contact details from them for the remainder of required respondents. A search of government departments and industry associations identified the appropriate respondents for these precincts. For the Australian precincts, senior public servants from within the G2 State departments were requested to nominate those senior public servants possessing deeper knowledge of the selected precincts to participate in the survey, noting that not all actor groups were present in all precincts.

Once the target list of respondents was established, they were approached via email to secure their participation. The email they received included the "Information Letter" and "Consent Form" as approved by the Murdoch University, Western Australia Ethics Committee (Approval 2022/140). A web-based survey instrument designed to obtain qualitative data from respondents having a direct role in a precinct's management or in the operation of the industries within it was sent to them. The method employed was to develop a checklist of questions encompassing the four posited dimensions and, utilising the instrument, characterise the precinct against each of these. Once agreements to participate were received, the survey instrument was made available for data entry. Where a respondent had not entered their data, follow up telephone calls were made to those individuals, with an offer to participate in a verbal interview which would result in the data being directly uploaded into the software.

The purpose of the research was to develop a process to test the efficacy of the posited KIC4 tool itself, and not to provide a detailed analysis of any particular precinct. In other words, did the data gathered produce a dimensional profile for a given industrial precinct that could be considered a good characterisation of that precinct? Did the application of the model raise awareness and create knowledge about the specific factors that were constraining or supporting a chosen precinct, and potentially, therefore, the steps to take in response to this knowledge?

Dimensional scoring method

The four KIC dimensions (D1-D4) are defined as:

- **D1 Materials Exchange**. This means the primary products that are manufactured for use within a precinct, and by-products produced as a result, which are used by other enterprises within the precinct for their own manufacturing processes. Only re-used utilities such as waste steam or re-processed wastewater are included in this Dimension.
- **D2 Skilled Workforce**. This means the collective workforce that attribute their employment, be it direct or indirect, to the enterprises geographically associated with a precinct.
- **D3 Support Industries**. This means those enterprises in locations geo-

graphically associated with the primary enterprises located within the precinct, that attribute to a reasonable degree, the supply of goods and services to the resident primary enterprises.

- **D4 Governance**. This means the governmental environment within which the precinct operates (statutory, regulatory, common user infrastructure, etc.).

Each of the five corresponding IFs that were identified for each dimension are set out in Table 1. For their respective precincts, respondents rated the strength of each dimensional IF on a scale of 1 - 10, where 10 was the highest score. The total score per factor per dimension per precinct was calculated and averaged. This method provided empirical data detailing firstly the total and average score per dimension per precinct (all actor respondent groups together), and secondly,

Table 1. Influencing factors per dimension.

IF	D1	D2	D3	D4
1.	There are materials available for exchange within the precinct.	Generally, the enterprises in the precinct could be characterised as having a stable workforce, and usually with good ability to attract and retain skilled employees.	The support industries required by the precinct's primary enterprises are in close proximity.	There is a comprehensive strategic development plan to guide the future development of the precinct.
2.	Pipeline corridors (and services easements) to facilitate materials exchange are available.	It is generally understood that there is ample scope for employee skills enhancement and career progression within the precinct.	The range of goods and services, specialist and general, offered by the nearby support industry cluster meets the needs of the primary enterprises.	The overall management of the industrial area rests with a party, for example a government department, and there is a long term, respected, and participatory working relationship between the manager and the enterprises.
3.	Future materials exchanges are facilitated by or because of a third party.	Most of the precinct's workforce live within nearby residential communities located not more than 20-30 kms from their place of work.	The support industry cluster has shown that the enterprises can work together to build comprehensive bids in response to tenders put out by the primary enterprises.	The common user infrastructure (roads, rail, ports, pipeline corridors, industrial land, utility providers etc) that services the precinct is fit for purpose, thus not responsible for placing constraints on industry.
4.	Materials exchange is an attractive feature of the precinct.	Nearby residential communities have a good spread of family-orientated amenities – schools, recreational opportunities, community services etc.	The enterprises located within the support industry cluster are a training ground for future employees for the primary enterprises.	The precinct is protected from inappropriate land use encroachment through the presence of adequate buffer zones.
5.	A feature of the precinct is that some enterprises were established within it to provide input materials for the use of other nearby enterprises.	The precinct's enterprises broadly have a preference for employing local apprentices and trainees.	Support industry businesses have long term relationships with the precinct's primary enterprises.	The interests of the precinct's enterprises are collectively represented through an industry association.

the same information but identifiable per actor group per dimension, to enable the perceptional differences between the actor groups to be discerned.

4. Results and Targeted Observations

In this section an analysis of the data gathered during the research has been combined with some targeted discussion points to illustrate the application of the KIC4 model. This has been done sequentially on a per Precinct, per Dimension and per Group (combined and separated) basis by cutting the data in various ways to produce granular information, and to provide a demonstration of how the KIC4 model works when applied to a selected industrial precinct.

4.1. Response Data

Table 2 describes the four actor groups surveyed, noting the targeted number of respondents per group and the actual responses. Across the groups a maximum number of 63 respondents were possible, however some groups were not represented in the selected precincts. Taking this into account, there was a potential total of 60 possible respondents, with the actual total number of responses being n = 50, giving an overall response rate of 83%.

Each of the industrial precincts selected for the research were allocated an alpha code and characterised as follows:

1) Australian Marine Complex (AMC), Perth, WA. AMC is characterised by a mix of maritime (including navy defence) industries generally focused on the the engineering associated with subsea LNG extraction sector, although ship building/maintenance and resource sector fabrication also strongly featur (Regional Development Australia, 2020; Development WA, 2023c).

2) Burrup Peninsular (Bur), Pilbara, WA. Bur is predominently characterised by LNG-related extraction and refining operations, and in recent years has seen the establishment of LNG-associated industries such as fertiliser production (Development WA, 2023d).

3) Collie-Shotts (Col), Southwest, WA. Col is characterised by the older generation of coal-fired power stations. These are being progressively closed and the government is in the early stages of encouraging modern manufacturing enterprises to locate there (Development WA, 2023a).

4) Gladstone (GLA), Queensland, Australia. Gla is a very large and spread out

Table 2. Respondent characteristics and calculated response rate.

Group	Target	Potential	Actual	% Response
G1	1	9	8	89
G2	2	17	14	82
G3	1	7	7	100
G4	3	27	21	78
Totals	7	60	50	83

industrial area, with several sub-precincts located within (Gladstone Region, 2023). It is characterised by LNG extraction and refining for export, and a broad mix of traditional manufacturing and refining operations (Queensland Government, 2023).

5) Kalundborg (Kal), Denmark. Kal can be characterised by a relatively small number of diverse manufacturing enterprises which are substantially integrated via the exchange of materials (product and by-product) for mutual advantage. Pharmaceutical and enzyme manufacture and energy production are prominent activities (Chertow, 2000).

6) Kemerton (Kem), Southwest, WA. Kem is characterised by. small number of large traditional and modern manufacturing enterprises. These operations largely stand alone and the precinct has never really gained momentum as an industrial hub (Development WA, 2023b).

7) Kwinana (Kwi), Perth, WA. Kwi is characterised an extensive, mature and complex mix of heavy industrial uses, including traditional forms of mineral, metal and fuel refining, cement and chemical manufacture, and energy production. The precinct is well-regarded for its product and by-product exchanges. New enterprises from the electric battery upstream value chain are rapidly entering the precinct, propelling a new generation of modern manufacturing and renewable energy production industries into the region (Development WA, 2022; Regional Development Australia 2020).

8) Port Hedland (PtH), Pilbara, WA. PtH is characterised by the export of iron ore. This precinct is singularly focused on the efficient management of ore stockpiling and export to foreigh destinations (Pilbara Port Authority, https://www.pilbaraports.com.au/, 2023).

9) Port Kembla (PtK), New South Wales, Australia. PtK is characterised by by a complex mix of traditional manufacturing industries (Port Kembla Port Authority, 2023).

On a per Group (G1-G4) basis, **Table 3** summarises the number of respondents who participated in the survey. Note that from this point that the precincts are referred to by their alpha code.

Table 3. Tally of the number of responses per industrial precinct.

Code	G1	G2	G3	G3	Totals
AMC	1	2	1	2	6
Bur		1		1	3
Col	1	3	1	2	7
Gla	1		1	2	4
Kal	1		1	2	4
Kem	1	2	1	2	6
Kwi	1	2	1	3	7
PtH	1	2	1	3	7
PtK	1	1	1	3	6
Total					50

4.2. Industrial Precinct Characteristics

The data in Table 4 is quantitative, and its purpose is to set out for comparative purposes the characteristic differences between the various precincts. The questions were intended to tease out the differences and to begin to provide indicators as to any common characteristic(s) that could be associated with vibrant or weak precincts. The questions asked are listed below and they reflect the row numbering in Table 4:

1) What distance (kms) is it to the nearest main city?

2) In what approximate year was the precinct established?

3) What is the area (ha) of the precinct?

4) Does the precinct have direct access to a coastal port?

5) Does the precinct have room for expansion?

6) Is the management of the precinct predominantly a function of Government?

7) Do the enterprises in the precinct have a collective plan to move toward net zero carbon?

4.3. Most Important Factor(s) per Precinct

The respondents were asked to nominate which factor they considered to be the most important for each Dimension (D) (Table 5). Note that in this, and other tables following, where two or more precincts recorded an equal first score, these were presented as such (for example as in Col D1).

While reflecting that the two most highly regarded precincts based upon the amount of published literature are Kalundborg and Kwinana, and aside from the three equal first scoring IFs for Kwinana, alignment is observed between these two mature, complex industrial areas across the four dimensions. This alignment

Table 4. Characteristics of industrial precinct.

Characteristics/ Precinct	1	2	3	4	5	6	7
AMC	>5	2003	400	Yes	Yes	Yes	No
Bur	35, *1550	1990	1600	Yes	Yes	Yes	No
Col	30, *200	2010	210	No	Yes	Yes	No
Gla	>10	1993	27,000	Yes	Yes	Yes	No
Kal	>5	1960	280	Yes	Yes	Yes	Yes
Kem	4, *100	1985	2300	No	Yes	Yes	No
Kwi	>5	1955	2500	Yes	No	Yes	Yes
PtH	180, *1600	1980s	2000	Yes	Yes	Yes	No
PtK	>10	1930s	1500	Yes	Yes	Yes	No

*Primary location of precinct workforce.

is highlighted through the use of emboldened numbering for these two precincts. It will be presented later in this paper that they also rated highest across their KIC4 scores. In D2, IF1 and IF3 were common responses. In D3, IF2, rated prominently across the precincts. In D4, there was no clear common thread observed.

4.4. Highest Scoring (Combined Groups) Influencing Factors per Dimension per Industrial Precinct

Table 6 presents the most highly rated IF(s) identified by the combined groups per Dimension per Precinct.

To illustrate how to interpret the data on a per Precinct (column) basis, the highest rated factors across the combined groups for Gla were: D1 IF2; D2 IF4; D3 IF5; and D4 IF4.

Looking at the data in Table 6 on a per Dimension (row) basis presents the opportunity to compare the combined Group responses for each precinct, where some trends emerge. For example, D1 IF4 was selected by both Kalundborg and Kwinana, recalling that these precincts are acclaimed for their materials exchange profiles. At D2 IF3 and IF4 each were selected four times (44% each). At D3 IF5 attracted 66%, and at D4 IF4 attracted a strong majority, with 78%.

4.5. Highest Scoring (Individual Groups) Influencing Factors per Dimension per Industrial Precinct

Presented in Table 7 is the data from Table 6 separated into each of the four actor Groups. Thus, the highest scoring IF is presented on a per Group, per Dimension per Precinct basis. In this table the six WA precincts have been underlined to assist with illustrating certain interesting findings.

Table 5. Most important influencing factor per dimension (combined groups) per industrial precinct.

Dimension	AMC	Bur	Col	Gla	Kal	Kem	Kwi	PtH	PtK
D1	3	2	1.4	2	4	4	4	2.3	2
D2	1	3	3	3	3	3	1.3	1	1
D3	2	5	2	2	2	2	1.2	1	1
D4	2	3	1	1	4	2	3.4	1	3.5

Table 6. Highest scoring influencing factor (combined group).

Dimension	AMC	Bur	Col	Gla	Kal	Kem	Kwi	PtH	PtK
D1	1.4	4	5	2	4	2.5	4	3	5
D2	3	3	4	4	4	4	3	1.2	3
D3	1	1	4	5	5	4	5	5	5
D4	4	4	4	4	4	4	5	5	4

Table 7. Highest scoring influencing factor per industrial precinct.

Dimension and Group	AMC	Bur	Col	Gla	Kal	Kem	Kwi	PtH	PtK
D1 G1	1	2	2	2	4	1	4	2	5
D1 G2	4	2	5			2	1, 4, 5	2	5
D1 G3	5		5	5	1	5	1, 4, 5	3	2
D1 G4	5	2	2	2	1	1, 2, 4	1	5	4
D2 G1			1	3	3	1	3	4	2, 3, 5
D2 G2	1, 2	3	4			2	1	1	1
D2 G3	2, 3, 4, 5		3	4	1	3	2, 3, 5	1, 2	5
D2 G4	3	2	3	2, 3, 4, 5,	2	4	3, 4, 5	1, 2	5
D3 G1			1	2	2	2	1	1	1
D3 G2	1, 4	2	2			4	1, 4, 5	5	2
D3 G3	1, 4		4	2	2	2	5	5	3
D3 G4	3	5	5	5	2	5	5	5	5
D4 G1			4	1	3	2	1	4	4
D4 G2	1	2	4			4	5	4	2
D4 G3	4		3	1	3	3	5	5	5
D4 G4	4	4	3	4	3	4	5	3	4

- At D3 G4, 78% of respondents rated IF5 as the highest scoring, and of the WA IPs, the response was 83%.
- Across all dimensions, and comparing G2 and G4, there is only minor direct alignment between the two groups (Bur D1, Kem D4, Kwi D5, and PtH D3), indicating that what a precinct's enterprises believe to be the highest scoring factor is mostly at odds with the government respondents' beliefs.
- Similarly, between G1 and G2, there is only minor direct alignment between the two groups (Col D4, PtH D1, D4), indicating where both governmental groups are represented in the data, they predominantly hold differing views on the strengths of a given precinct.
- It is useful to observe the alignment across the three groups within Kal at D3 and D4.
- At D1G3, 66% of the WA precincts with an industry association present selected IF5. It is of interest that the G4 responses did not align with those of G3, and one may posit that G3 has a broader overview of the precinct.
- At D2, the scores reflected the highest incidence of "first equal" responses (8), indicating many respondents found it difficult to choose one above another.
- Across G4 there is reasonable factor alignment. Observe that where there is a G3 present, there is some direct alignment with industry views, an indication of the strength of the communications between these two groups.

- At Kwi, D4 G2, G3, and G4 aligned in their selection of IF5. Similarly, at PtH, G2, 3 and 4 aligned on IF5.

At this granular level, and other than the ratings similarities described above, it is observed that there is limited commonality of views between the groups and dimensions across the precincts as to the relative importance of a particular factor over another. The important point to reflect upon is that the responses from the respondents reflect their different perspectives, and that the existence of the differences can be an be used as an initiator of discussion between the actor groups.

4.6. Additional Comments by Respondents

Table 8 tallies the number of open-ended comments about each Dimension. There was a total of 117 comments recorded. There was a willingness to share views, and such commentary would provide a rich source of material to feed into possible precinct improvement discussions between the groups.

Table 8. Tally of the number of additional comments by respondents.

Dimension	AMC	Bur	Col	Gla	Kal	Kem	Kwi	PtH	PtK	Totals
D1	3	2	6	3	3	34	4	4	3	31
D2	2	2	3	3	3	4	4	3	4	28
D3	1	1	4	1	3	4	4	3	1	22
D4	3	2	7	3	3	4	4	4	6	36

Table 9. Tally of the number of improvement suggestions per industrial precinct.

Dimension	AMC	Bur	Col	Gla	Kal	Kem	Kwi	PtH	PtK	Totals
D1					1					1
D2		1			1		1			2
D3	1		2			1				4
D4		1			1		1			3

4.7. Suggestions for Precinct Improvements by Respondents

Respondents were asked to identify two or three major things that could be implemented to significantly improve the ability of the precinct to perform in a way that would enable the resident enterprises to improve their international competitiveness. Table 9 provides a tally (85) per dimension per precinct with only a minimal contribution coming from Groups 1, 2, and 3, and with the remaining 90.5% emanating from G4, this is an indication that asking the resident enterprises for precinct improvement suggestions was very productive and a rich source of ideas.

4.8. Supportive or Constraining Factors per Group per Dimension

Figure 3 presents the numerical assessment of the dimensions, and the extent to

Port Hedland industrial precinct constraining and supporting Influencing Factors

PtH	IF1	IF2	IF3	IF4	IF5	Total (50)
D1						
G1	3	5	6	4	3	21
G2	4.5	6.5	4.5	4.5	4.5	24.5
G3	3	2.5	6	2.5	2.5	16.5
G4	3	3	2.5	2	3.5	14
D2						
G1	5	6	3	2	3	19
G2	8.5	8	2.5	6.5	6.5	41
G3	9.5	9.5	6	8	8	31
G4	8	8	2	6	7	31
D3						
G1	7	7	8	7	7	37
G2	8	8	7.5	8	8.5	40
G3	7	7	5	7.5	8	34.5
G4	7.5	7.5	8	7.5	9	39.5
D4						
G1	3	7	4	7	8	29
G2	7.5	8.5	8.5	9	8	41.5
G3	5	3	4.5	3.5	9	25
G4	2.5	3	3.5	3	2	14

Legend	
6.5 - 10	Supporting Influencing Factor
4.6 - 6.4	Neutral Influencing Factor
0 - 4.5	Constraining Influencing Factor

Figure 3. Port hedland constraining and supporting influencing factors and quartile allocations.

which each Group in each Dimension viewed an IF as a constraining influence (orange, 0 - 4.4), or supporting influence (green, 6.5 - 10), with an assumed range of neutrality being in the middle (blue, 4.5 - 6.4). The Group score per IF was the average of the scores recorded in the data, where each of the five IFs per Group scored a rating of between 1 and 10, thus for each Group the maximum possible score was 50.

PtH D1 G1 shows the total of the factor averages is 21, or 42% of the maximum possible score of 50.

The following is a broad summary of what the PtH data illustrates:

D1: All Groups agreed that the degree to which D1 is operating within PtH is a constraining factor within the precinct. Each of the four Groups could potentially play a role in improving this characteristic.

D2: By and large D2 was supporting the enterprises in PtH, however this was not the view held by G1. There were some factors (G2 IF4, G2 IF5) indicating improved performance was achievable.

D3: Several of the scores were only a little above the assumed neutral score, yet there was common agreement that within this Dimension, the IFs were supporting the PtH precinct.

D4: The data in this profile presented a D4 profile that was observed in several other precincts surveyed. In essence, the government sector (G1, G2) perceived that the precinct was providing a supportive environment (the government sector in all WA cases is the "owner" of the precincts), while the industry sector (G3, G4) strongly held the opposite view, that the precinct's D4 was a constraint on their ability to operate competitively.

4.9. Introducing Quartile ratings per Dimension

In Figure 4, D1: is the Materials Exchange; D2: Skilled Workforce; D3: Support Industries; D4: Governance, and, G1: is the national (federal) government; G2: provincial (state) government; G3: industry association; and G4: is the actual enterprises. Dimensional quartile (Q) ratings were presented in a heat map format. When a score is expressed as a percentage of 50 (the maximum possible score for each of the five IFs per Dimension) this provided a Q-rating for that Group in that Dimension. Quartile percentages are described as: Q1: 1% - 25%, Q2: 26% - 50%, Q3: 51% - 75%, and Q4: 76% - 100%. The percentage per-group per Dimension is averaged to provide the per-dimension Q-rating. In this way the PtH D1 averaged score of 38% delivers a Q2 profile. This approach provides the ability to see immediately where the strengths and weaknesses of a precinct lie, with the more intense colour indicating greater dimensional strength.

4.10. Precinct Profiles

Presented in Figure 5 are the KIC4 Dimensional profiles for all nine of the precincts researched. These profiles were obtained using the same process as in the

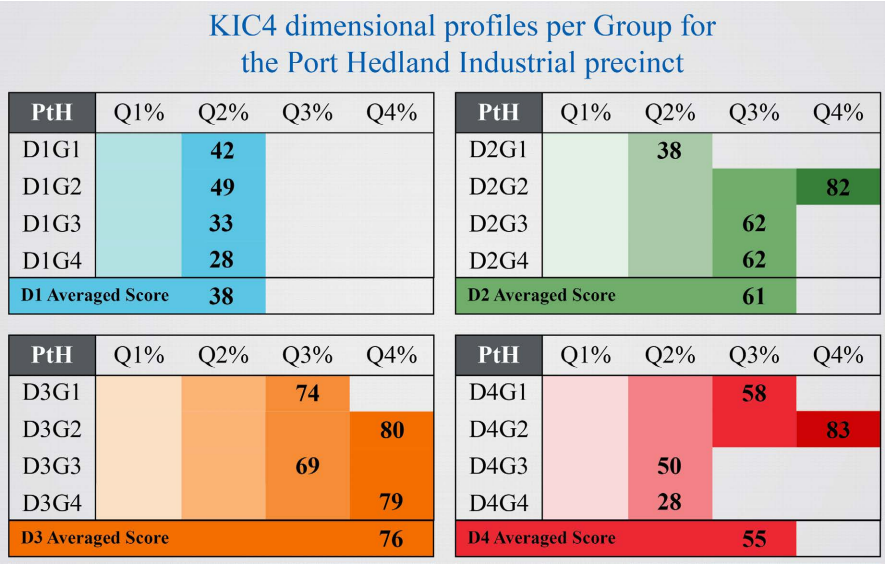


Figure 4. KIC4 Dimensional profiles per group for the port hedland industrial precinct.

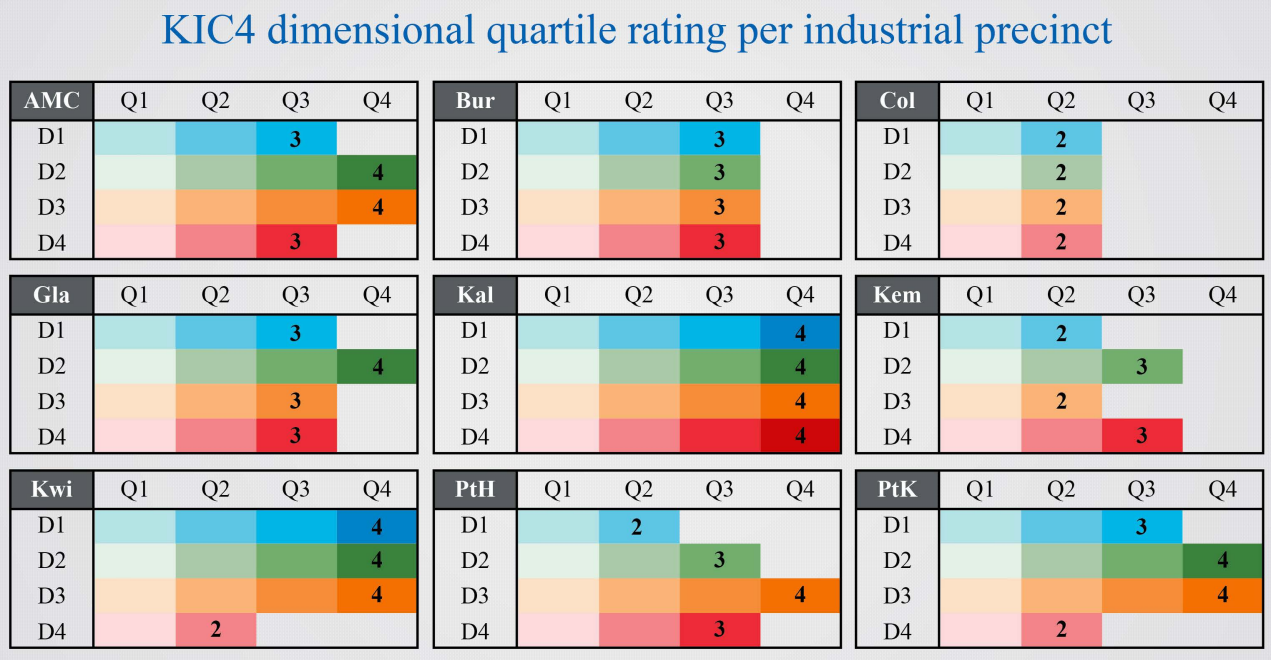


Figure 5. Dimensional quartile rating per industrial precinct.

previous PtH example.

In the analysis for the two benchmark precincts, Kalundborg delivered a dimensional profile that matches its reputation (top quartile across all four dimensions), whereas the profile for the Kwinana precinct fell short at Dimension 4 Governance. With the application of published local knowledge, the reasons for this may be explained.

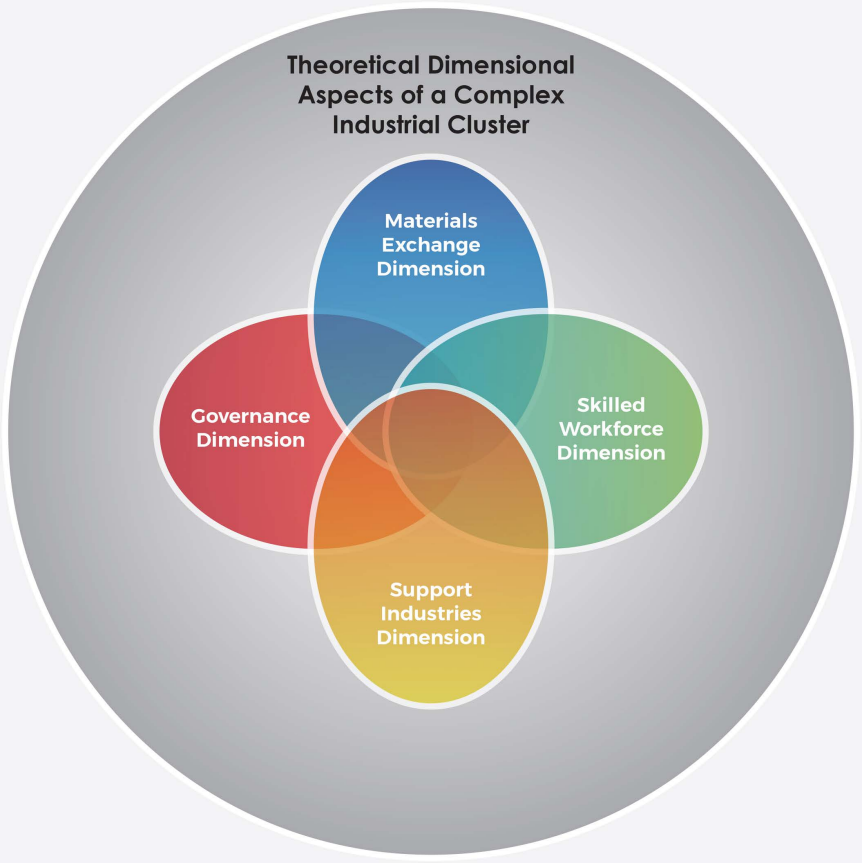
4.11. General Discussion

In earlier research, dysfunctional relationships were observed at Kwinana, specifically in the interaction between the collective enterprises and the relevant public service departments (Oughton et al., 2021). The example given was where a major and important process water re-use initiative for industry failed because a departmental stakeholder raised a new project risk during the final meeting of the 2-year process, resulting in the project being abandoned. During subsequent research it was observed firstly that respondents generally felt nervous in expressing their views about the performance of the Industry Regulator (likely negative), and secondly, that it was a business risk to do so because there could be future repercussive effects on an enterprise's relationship with that Regulator (Oughton et al., 2023b). Based on the response rate, that research identified the existence of a problematic relationship between the industrial enterprises and various government departments, as 30% described the relationships as inflexible, and 40% were not willing to provide comment. The KIC4 dimensional profile produced through the application of the model (**Figure 5**) at Kwinana reinforced the findings of the earlier research.

This outcome provides an example where a weakness in the governance di-

mension translates into a diminished opportunity to firstly, expand the Dimension 1 materials re-use exchanges and secondly, to reduce an expansion of the Dimension 3 support industry service base. In taking this discussion point further, and to illustrate the interconnectedness (**Figure 6**) of the four-dimensional synergistic relationships that underpin the KIC4 framework, Harris argues that supportive policy settings (governance dimension) can be used to encourage and support (through incentives) initiatives (such as for example the Kwinana water re-use project) (Harris et al., 2018). Aid takes a stronger position positing that regulatory requirements (that ultimately ended the water re-use project) can be a major barrier to the implementation of IS (materials) exchanges (Aid et al., 2017). They described these as being a direct hinderance through legislative blocking, demanding through difficult permitting processes, or unsupportive through unclear legislation. Neves holds a similar view, where legislation and existing policies were identified as influencers of IS practices (Neves et al., 2019).

A strength of the KIC4 framework is that in the identification of the source of issues through an understanding of the interconnectedness of the dimensions can expose the actual sources of issues and pathways to their resolution, with some of these sources being indirectly related to a particular dimension.



Source: Oughton et al. (2022).

Figure 6. Depiction of an industrial precinct across the KIC4 Dimensions of Industrial Symbiosis.

5. Conclusion

The KIC4 model (Figure 7) by its nature was designed to deliver a quantitative interpretation of the opinions from the range of actors associated with any given industrial precinct. This approach has delivered useful qualitative commentary about any underlying issues and suggestions for potential precinct improvement. In contrast, any attempt to quantify the Dimension 1 materials exchanges (volumes, weights and prices) was out of scope for this research project as this would be a major research project in and of itself, and would be expected to come up against commercial in confidence barriers to data collection.

5.1. Applications for the KIC4 Model

There are several applications the model may be used for, and the first of these is where the owners or managers of industrial precincts can evaluate their precincts to understand what improvements are needed to make them more attractive to new entrants, to understand if there are any underlying reasons behind perhaps a precinct's poor reputation, or to find out what may be constraining the commercial efficiencies of the enterprises located within it to make it clearer how the precinct can be made more conducive to business. Often the government sector is the owner/manager of these precincts, and knowledge about

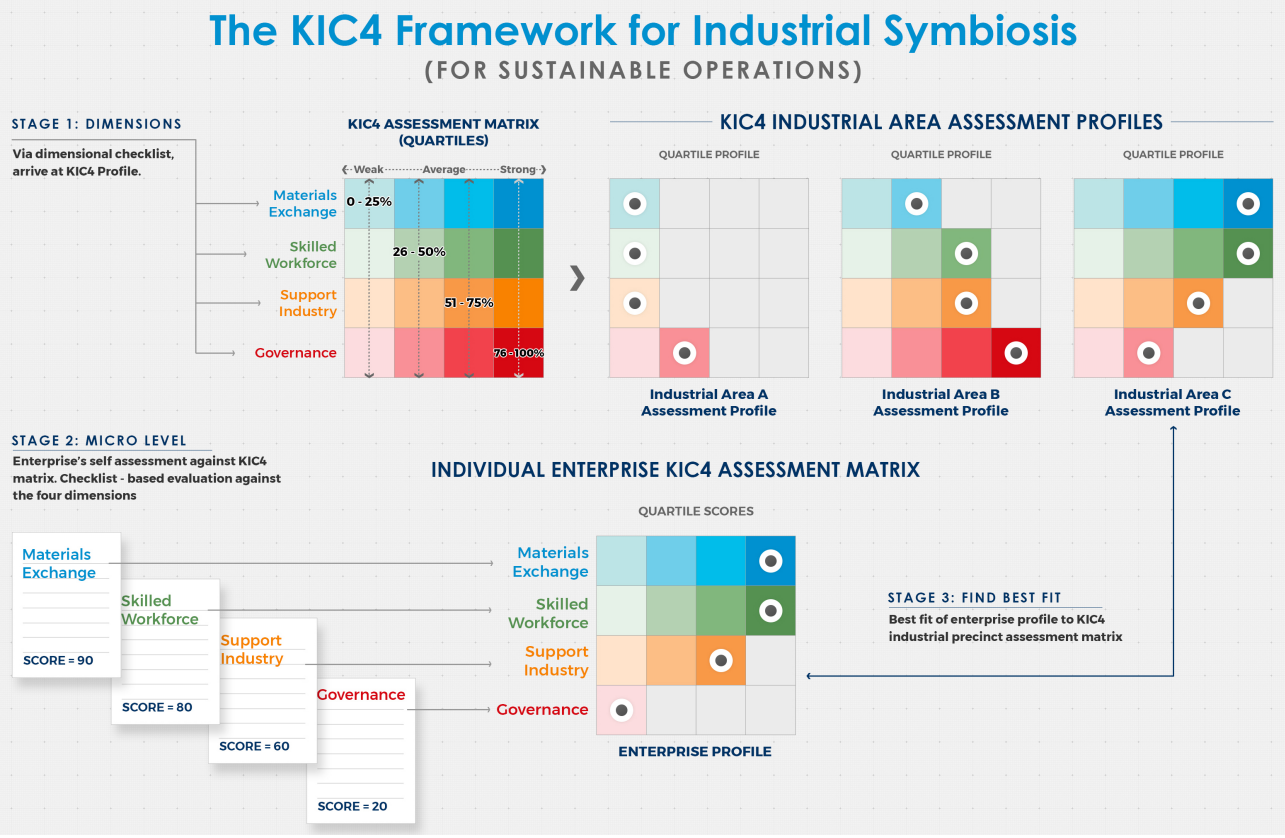


Figure 7. Application of the KIC4 model for use in matching the dimensional needs of an enterprise with a suitable industrial precinct.

constraining and supporting influencing factors can assist with forming industry-related policy, in statutory land use planning activities, and establishing funding priorities for common user infrastructure investment. Industry associations can use the same data about the influencing factors to develop a prioritised set of goals to build an advocacy strategy to better represent the interests of its member enterprises to the government sector, for example to facilitate a collegiate goal such as carbon reduction, enhancing its skilled workforce base, or upgrading common user infrastructure such as an aspect of the freight transport network. At the individual enterprise level, this same information can be used in the development of a targeted government relations advocacy agenda, to motivate policy change to for example better facilitate the building of new materials exchange opportunities through regulatory change. Alternatively, a prospective new enterprise precinct entrant might find it useful to better understand its own KIC4 profile so that it can better match its individual company needs to that of a range of alternative precincts, and to locate the one that best matches its individual profile.

In the business world, the KIC4 model provides an objective and comparable process as the basis for benchmarking between precincts to identify improvement strategies, and the consulting industry can use it as a tool in the assessment of precincts to provide a formal basis for recommendations to clients. In academia, the model can be used in the tertiary education of students in the field of for example, Industrial Sustainability or Circular Economy, and how the strengthening of an industrial precinct's ability to be more conducive to business may be achieved. Additionally, students from within associated fields of study might use the model to assist with precinct case studies to develop theoretical improvement plans for the precinct owners, or to carry out benchmarking activities working with university partners to assess and compare precincts.

5.2. Concluding Observations

We found that those precincts that were identified as being well-regarded in the published research and which were also identified for the research (Kalundborg and Kwinana) exhibited similar characteristics to many of the other precincts selected, but those characteristics that consistently set them apart were that they were mature (established 1955-1960), they had a long-term and very strong materials exchange network, their skilled workforce lived in nearby communities as close as only 5 kms away, they were located on the coast with access to port infrastructure, and they had a mature representative organisation providing advocacy and the governance for (for example) their collective carbon reduction planning. Through the research and application of the KIC4 model, the presence of the support industries located in close proximity to the precincts was also a locational factor.

The purpose of this paper then, was to test to what extent the symbiotic dimensions of a precinct, each supported by a series of influencing factors, impact its ability to facilitate the advancement towards CE outcomes for its resident en-

terprises, and to provide an environment for facilitating strong commercial sustainability. This purpose raised two primary research questions which were: What are the influencing factors that support each dimension of the KIC4 model, and does the KIC4 model provide a reliable process by which it can be replicated by others to deliver accurate dimensional precinct profiles?

In answer to the first question, a set of 20 key influencing factors was identified and developed, with five purposefully designed allocated to each of the posited four dimensions of Industrial Symbiosis, these being Dimension 1 Materials Exchange; Dimension 2 Skilled Workforce; Dimension 3 Support Industries; and Dimension 4 Governance. These factors were tested across nine selected industrial precincts through the application of a web-based survey instrument designed to obtain quantitative data from respondents having a direct role in a precinct's management or in the operation of the industries within it. The method employed was to develop a checklist of questions extending across the four dimensions, and after obtaining a rating score for each factor, characterise the selected precincts against each of the dimensions.

In answer to the second question, the model was tested against nine distinct industrial precincts. Analysis of the results delivered dimensional profiles for each and it demonstrated that there was a reliable process sitting behind the model and that it could be replicated consistently. The survey instrument itself will be published in the completed thesis for which this paper is the last in a series of five scholarly papers.

The authors can conclude that the reason for the relative strength or weakness of an industrial precinct, or that the extent to which the precinct is conducive to business, is described under a four-dimensional framework which has been called the KIC4 Dimensional Model of Industrial Symbiosis. The evidence confirmed that this model can be used to enhance the design of complex industrial precincts to assist enterprises with achieving high levels of circularity and production efficiency, or the re-design of precincts through the identification and addressing of constraining Influencing Factors. In satisfying the research objectives, it can be concluded that the KIC4 model delivers an applied tool for the evaluation of any given industrial precinct across twenty Influencing Factors divided evenly between the four dimensions of Industrial Symbiosis.

It is suggested that this research presents many pathways for future research and practical application, and it is acknowledged that future research may review the KIC4 model and identify additional dimensions and their associated influencing factors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

CE	Circular Economy
D	Dimension (1, 2, 3, 4)
G	Group
IF	Influencing Factor
IS	Industrial Symbiosis
KIC4	Four-dimensional framework
Q	Quartile
WA	Western Australia

Industrial Precincts Surveyed Are

AMC	Australian Marine Complex, WA
Bur	Burrup Peninsular, WA
Col	Collie-Shotts, WA
Gla	Gladstone, Queensland, Australia
Kal	Kalundborg, Denmark
Kem	Kemerton, WA
Kwi	Kwinana, WA
PtH	Port Hedland, WA
PtK	Port Kembla, New South Wales, Australia