QUANTIFYING ‘GEOGRAPHIC PROXIMITY’:

Experiences from the United Kingdom’s National Industrial Symbiosis Programme

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Abstract

Geographic proximity is said to be a key characteristic of the resource reuse and recycling practice known as industrial symbiosis. To date, however, proximity of symbiont companies has remained an abstract characteristic. By conducting a statistical analysis of synergies facilitated by the United Kingdom’s National Industrial Symbiosis Programme during their first five years of operation, this article attempts to quantify geographic proximity and in the process provide practitioners with an insight into the movement trends of different waste streams. Among other it was found that the median distance materials travelled within a symbiotic relationship is 20.4 miles. It is argued that quantitative information of this form is of practical value for the effective deployment of industrial symbiosis practitioners and wider resource efficiency planning. The results and discussion presented within this article are specific to industrial symbiosis opportunities facilitated within the United Kingdom; the methodology and assessment of resource movement influences are, however, expected to be relevant to all countries in which industrial activity is similarly mature and diversified.

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1. Introduction

1.1 *Industrial Symbiosis and the National Industrial Symbiosis Programme*

Industrial symbiosis can be regarded as the establishment of close working agreements between normally unrelated companies that lead to resource efficiency. Working agreements include, among other, the direct reuse of one company's waste stream as another's raw material, the innovative reprocessing of problematic by-products, and the sharing of underutilised power, water and/or steam.

Specific reasons for the establishment of industrial symbiosis agreements, otherwise known as synergies, are manifold. Apart from the business imperative of needing to improve profitability and competitiveness, drivers of symbiosis can also be social, environmental and/or regulatory in nature (Chertow, 2007). Within the UK, synergies are facilitated by the National Industrial Symbiosis Programme (NISP) as part of a deliberate attempt to encourage industry to look beyond their traditional markets for business opportunities capable of delivering resource efficiency.

Not restricted to working within geographic boundaries, such as individual industrial estates or municipalities, NISP is a Government supported private sector initiative charged with the national promotion and delivery of industrial symbiosis¹. As of February 2010, NISP had recruited almost 13,000 member companies which are collectively served by 12 regional delivery teams located throughout England, Scotland, Wales and Northern Ireland. Engaging with companies on a "work with the willing" basis (H. Hitchman, Pers. Comms., 2010), NISP facilitated industrial symbiosis has helped to generate significant economic and environmental benefits for both Programme members and the UK Government (see Laybourn and Morrissey, 2009).

Though not every NISP member is currently engaged in an active synergy all have contributed to the Programme by way of supplying industrial resource flow data. Indeed, one of the by-products of NISP's delivery of industrial symbiosis is the generation of a significant amount of data pertaining to the production and management of industrial waste. NISP and their affiliated researchers are continually evaluating the data they possess in the pursuit of developing industrial symbiosis best practice. This article presents the results of one such study into the spatial movement of resources between NISP members.

¹ The reciprocal 'top-down' influence of the UK Government and 'bottom-up' needs of the private sector that have helped to shape the NISP delivery model, can be likened to the 'middle-out' approach to industrial symbiosis development discussed by Costa and Ferrão (see Costa and Ferrão 2010).

1.2 Industrial Symbiosis and 'Geographic Proximity'

As there is still some disagreement as to what differentiates a synergy from 'everyday' exchanges of resources (as evidenced by discussions held each year at the Annual Industrial Symbiosis Research Symposia and discussed briefly in Chertow, 2007: 12), it is sensible to clarify what constitutes a synergy within the context of this article. The working definition employed within this article derives directly from the biological description of symbiosis (e.g. Begon et al., 2006; Chapman and Reiss, 1999). Simply, the physical exchange of operational resources between distinctly unrelated companies, or sectors, constitutes a synergy. To be clear, a symbiotic partnership is effectively the opportunistic coming together of two or more actors from sectors that, under normal circumstances, would not come into contact and consequently would not necessarily possess a working knowledge of each other's operational processes. The mode of a given synergy, whether mutualistic or commensal, is defined by the outputs of the synergy and the specific objectives of the actors involved. For example, where all symbionts clearly derive tangible benefits from a synergy, mutualism is observed. Where a company freely donates a serviceable and/or saleable resource to another company or organisation (e.g. for philanthropic reasons) the tangible benefit of the synergy is wholly felt by the resource recipient and thus commensalism is observed. Though mutualism is the most prevalent and arguably preferential mode of industrial symbiosis, there is no specific requirement for a synergy to be mutually beneficial.

A widely agreed and therefore often cited element of industrial symbiosis theory is, however: "...the synergistic possibilities offered by geographic proximity" (Chertow, 2000: 314). Apart from the obvious economic and practical benefits of local collaboration, the close proximity of potential symbiont companies is said to ease the development of trust and cooperation - two components that are believed to be prerequisites of any form of eco-industrial agreement (Hewes and Lyons, 2008; Sterr and Ott, 2004; Wallner, 1999). Trust and cooperation are said to be important to symbiosis because, without it, companies are unwilling to link processes in a manner that may affect the ways in which they choose to operate (Gibbs, 2003; Lambert and Boons, 2002). Trust can also be a key influence on the development of symbiotic networks as it helps to embed and maintain the level of relationships required to develop and distribute knowledge and technology (Murphy, 2006). Without trust and cooperation the level of knowledge exchange required to facilitate symbiosis is both difficult and costly to obtain (Christensen, 1994, cited in Ehrenfeld and Gertler, 1997).

Importantly, the cultural or deliberate development of trust and ready collaboration amongst a network of potential industrial symbionts is believed to reduce “mental distances” between companies (Ehrenfeld and Gertler, 1997: 74; Gibbs and Deutz, 2007: 1689). Though the physical distances involved in a given synergy could be considerable, and thus potentially more problematic to facilitate than the outputs of any resource exchange is ‘worth’, the suggestion is that distances psychologically, if not physically, reduce if a relationship already exists between prospective symbionts. Though the supposition that reduced mental distances help to facilitate symbiosis is sound and well documented within eco-industrial planning literature, it is, however, not something that can readily aid the delivery of industrial symbiosis in a more strategic, targeted, and not least, cost-effective manner. To put it plainly: *short* mental distance and *close* geographic proximity are meaningless terms in relation to the active planning and facilitation of by-product exchanges. To improve a practitioner’s ability to identify opportunities for industrial symbiosis, it is useful for them to be guided by and/or able to refer to quantitative synergy facilitation information. For independent industrial symbiosis practitioners who work on any scale greater than that of a physically or politically bounded industrial estate, deciding where to look for a partner for a prospective symbiont requires specific information on the spatial movement dynamics of a given resource.

Despite the numerous years of research that have been conducted into the development of symbiotic networks, quantitative information on the movement of resources is scarce. Arguably this is due to the simple acceptance that the physical movement of some resources, such as utilities, will always be restricted. Whilst within regional eco-industrial studies there is the common-sense belief that high value by-product exchanges should not be “spatially constrained” (Chertow et al., 2008: 1304). Indeed, it is accepted that some high value by-product exchanges may take place over several hundreds of kilometres (van Berkel, 2006). Is there any evidence, however, to corroborate these assumptions that can be applied to the deliberate development of an eco-industrial network? Despite an extensive review of the relevant literature, it has not been possible to find proof to validate these apparently sound, yet empirically unproven, statements. It could be argued that it is, perhaps, not necessary to ascertain the distances involved in utility based synergies as there is, on a case by case basis, a specific measureable limit to where one can look for potential recipient symbionts. In the case of materials, however, knowing how far a given material tends to travel within eco-industrial agreements, rather than how far they can theoretically travel before losing their residual economic and/or environmental value, is, potentially, of significant interest and practical planning use.

Though it is relatively easy to determine the distances involved in resource exchanges, it is, seemingly, rarely done. If any distances are obtained, specific figures are seldom provided within articles; particularly within articles relating to the development of regional eco-industrial systems. That said, a recent study into the evolution of the Tianjin Economic-Technological Development Area (TEDA), China, did consider the specific distances involved in the movement of materials. On average it was shown that the distance between companies involved in the symbiotic exchange of materials was 28.2 km (Shi et al., 2010: 196). When the identified synergies were broken down to material exchanges solely involving TEDA based symbionts, the average figure for material movements fell to 11.5 km. The average distance materials moved between a TEDA based company and a company based outside of the TEDA boundary was found to be 34 km (Shi et al., 2010: 196).

The material movement statistics from the TEDA study provide interesting reading in relation to proactive implementation and nurturing of industrial symbiosis; particularly in comparison to the NISP model of national symbiosis delivery when it is revealed that the majority of TEDA synergies are cross-boundary (59%). With further analysis it would be useful to determine, if possible, why and what materials are moving cross boundary and why and what materials stay within the TEDA boundary. There may be no material specific trends to be uncovered; however, possessing knowledge of these further details could help industrial symbiosis facilitators develop resource specific management models and, furthermore, append a quantitative platform to the notion of ‘geographic proximity’. Accordingly, this article will continue by presenting the results of a study into the movement of materials within NISP facilitated synergies. Material movement statistics will be provided for all resources and also material specific exchanges. Also provided is an interpretation of what factors dictate the specific resource movement distances presented herein.

2. Methodology

2.1 NISP Data Collection

After speculative contact has been made between a company and NISP², practitioners are typically invited to visit a company and discuss potential solutions to their waste production and management problems. Initially discussions are problem specific; however, talks with potential symbiont companies are gradually directed by practitioners toward

² Initial contact between practitioners and companies can either occur directly on a one to one basis or via multiparty industrial symbiosis workshops.

acquiring a holistic knowledge of a given company's operational practices. Meeting proceedings are duly recorded and all 'have/want' potential resources identified by the company and the practitioner (whether they be expertise, by-products, waste streams, and/or excess utilities capacity) are registered on NISP's central database: CRISP (Core Resource for Industrial Symbiosis Practitioners). When registering resource details, all entries into CRISP are manually assigned generic waste stream titles prior to taxonomic assignment to three increasingly refined resource categories³.

As and when resource matches are identified and duly facilitated, the social, economic and environmental outcomes of the synergy are calculated, recorded and 'signed-off' by the NISP practitioner and symbiont companies prior to third-party verification of synergy outputs. Full details of completed synergies and their outputs are entered into the completed matches section of the NISP central database and assigned a unique Match ID number. Recorded synergy outcomes include: amount of landfill diversion, reductions in virgin material use, reductions in CO₂e emissions, industrial water savings, hazardous waste elimination, jobs saved and/or created, cost savings, additional sales and any new private investment⁴.

To ensure uniformity of data input, synergy facilitation data is entered on to the central database in accordance with NISP best practice guidelines. All data within the central database can be exported to queryable database formats for analysis, development of best practice resource management and/or auditing purposes.

2.2 Data Preparation and Calculation of Synergy Distances

A dataset of 979 completed and signed-off synergies for England, Scotland and Wales was generated (in December 2009) and exported from CRISP to dbf format⁵. To ensure that the distances measured only related to the physical movement of resources from one organisation to another, all non-material/substance based synergies were removed from the

³ NISP's bespoke waste stream categories were generated via the amalgamation of several existing waste classification systems and roundtable discussion amongst NISP' data analysts and practitioners.

⁴ Synergy outputs calculated and recorded are those required by NISP funding bodies, i.e. the Department for Environment, Food and Rural Affairs and the respective regions' Regional Development Agency (see Laybourn and Morrissey, 2009, for further information on Programme outputs reported for the period 2005-10).

⁵ The dataset of 979 synergies relates to the Programme's first batch of audited synergies. At the time the dataset was constructed (December 2009), NISP were engaged in the active facilitation of a further 3,782 synergies. Information relating to the movement of resources within Northern Ireland was not available at the time the dataset was generated.

dataset. For example, synergies pertaining to the sharing of expertise, shared labour, shared logistics and land were removed along with any data that had been assigned to a NISP regional office rather than the geographic location of a given company. This dataset of resource exchanges, which following the editing process related to 792 synergies, was broken down further to show only Match ID, company postal codes, resource stream titles, resource quantity and synergy outputs.

Employing MapInfo's PostPoint Professional, a postcode grid reference database for the UK (accurate to within 1 metre of the central address of a given postal code), each line of data within the synergies dataset was georeferenced. Where company postcodes could not be automatically georeferenced via the PostPoint Professional database, a national grid coordinate was manually acquired for the relevant company and applied to the synergies dataset.

The georeferenced dataset was imported into a Geographic Information Systems (GIS) software package (ArcGIS 9.1). Employing the 'Add XY Data' tool within the ArcGIS mapping extension, ArcMap, point features (data points) for each symbiont company were plotted (see Figure 1).

Fig. 1 Resource Exchange Network for the Analysed Dataset
of NISP Facilitated Synergies

To enable data querying and editing, the point feature data file was exported to ArcGIS shapefile format and reapplied to ArcMap for spatial analysis. Using the Match ID numbers assigned to each unique synergy, distances (in miles⁶) between partner symbionts were

⁶ Due to the nature of ongoing NISP research, distances were necessarily measured in miles (One mile = 1.609 kilometres).

automatically generated and appended to the shapefile's attribute table via a bespoke GIS 'Calculate Movement Parameters' tool (created by Beyer, 2004).

The shapefile's attribute table was exported back to dbf format for generation of resource movement statistics and analysis. To enable movement analysis of specific resource types, the dataset was disaggregated into NISP's bespoke waste stream taxonomic categories. In addition to distance statistics being generated for all material synergies and for resource specific synergies, statistics were also separately generated for any resources that contained hazardous material. To determine which factors might be influencing the distances involved in the spatial movement of materials, an analysis was also conducted on the relationship between the quantities of materials being exchanged and the economic value of each completed synergy. The process of data collection, analysis and application to Programme development is illustrated in Figure 2.

Fig. 2 Schematic of the Methodology for Generating Resource Movement Statistics and Application of Research Findings to NISP Development

3. Results & Discussion

3.1 Synergy Distances

In the first instance, resource movement data were analysed using a 5 mile frequency distribution of all synergies. Due to the presence of anomalous outlying distances creating a non-normal distribution, medians were selected as the appropriate statistic to represent average resource movements. As shown in Figure 3, the cumulative frequency curve for all NISP synergies indicates that a quarter of all resources are reused or recycled within a 9.6 mile (15.4 km) radius of production; whilst half and three-quarter of all resources are reused or recycled within a 20.4 mile (32.6 km) and 39.1 mile (62.6 km) radius of origin respectively⁷. Remembering that NISP operate on a national basis, and thus are theoretically capable of matching companies from anywhere in the United Kingdom to a resource located anywhere else in the country (and beyond), these can be deemed “surprisingly” short distances (H. Hitchman, Pers. Comms., 2010). Indeed, Figure 3 suggests that, in relative terms, the long-distance movement of materials is an unusual occurrence as over 90% of synergies are seen to have been facilitated within a 75 mile radius of resource origin⁸. Due to NISP being delivered by regional teams it could be argued that this range of figures would be expected and thus not surprisingly low at all; particularly bearing in mind that geographic proximity is considered a “hallmark” of industrial symbiosis (Shi et al., 2010: 197). However, it has to be recognised that all data on the CRISP system is visible, and thus available for synergy facilitation, to every practitioner working within the Programme. Maximising resource reuse and meeting associated funding targets are a priority for NISP. Thus distances between potential symbionts at the planning stage are, to a certain extent, irrelevant as all symbiosis options must be considered.

⁷ Due to ongoing NISP research into the geospatial distribution of industrial sectors, distances between symbionts were measured directly. As the work presented here feeds into a number of other (to be published) studies where it is essential to consider the Euclidean distance, these distances rather than distances travelled via the road network are presented here. For comparative purposes a parallel study into road mile distances was undertaken: the distances recorded did not contradict the overall trends or conclusions of the presented research. The average road distance travelled by materials is 25 miles (40 km).

⁸ For perspective: when measured directly from north to south, the UK is approximately 700 miles in length. The direct distance between the two major capital cities, London and Edinburgh, is approximately 331 miles.

Fig. 3 Cumulative Frequency Distribution of Resource Movement Distances
Shown as a Percentage of all Analysed Synergies

When the dataset of synergy distances is disaggregated into material groupings (see Table 1 and Figure 4), it can be seen that the average (in this case, median) movement distance of 20.4 miles for all synergies is not influenced by any one material; averages for individual waste streams remain generally consistent. Arguably, to confirm this supposition, the resource streams employed to determine individual material movements could be broken down further. For instance, there are numerous criteria that could be employed to disaggregate NISP's Metals or Inorganic Chemicals stream categories that may provide slightly different resource specific distances; however, taking the entire dataset into consideration, it is unlikely that any differences in distance would be statistically significant.

The analysis of synergy movements show that only man-made textiles, inorganic chemicals and rubber move, on average, further than the 39.1 mile upper quartile radius of all synergies. The trend of problematic man-made compounds travelling further than the upper quartile average is arguably to be expected. Breaking these materials down to their respective elements is not always possible; thus, NISP practitioners are restricted to finding a direct reuse for these materials or having to develop an innovative recycling process that will allow the constituent elements of the respective resource to be reused. One could intuitively argue that waste streams such as textiles moving further than high value materials (such as metallic wastes) does not make sense as it goes against widely held resource movement theory. Arguably, however, it is more logical for a difficult to reuse material to travel further, on

average, than a high value material because there are typically fewer industries capable of directly reusing the material or willing to absorb the expense involved in developing an innovative recycling technique. Thus, the chances of a symbiont company being in close proximity to another company looking to move on materials that have few reuses, or little residual economic value, are significantly reduced. To avoid the undesirable environmental and financial costs of landfilling within the UK, it makes sense for a donor company, who possess a problematic waste product, to personally absorb the relatively low costs of 'long distance' transportation (and potentially write-off any minimal value retained by the material) if it will lead to resource reuse rather than disposal.

The trend of only problematic wastes travelling further than the upper quartile distance for all synergies appears to be applicable to all of the waste categories presented within Table 1 and Figure 4. For example, the maximum distances recorded for the Infrastructure (199 miles) and Paper and Cardboard (269 miles) stream categories relate, respectively, to the reuse of underground recyclate containers that, due to planning restrictions, can only be used in certain areas of the UK, and waxed paper heavily contaminated with glue (which is a difficult material to reuse). Even the maximum distances found within the Hazardous Waste category, which has a surprisingly low average resource movement (given the potentially problematic nature of the material) of 26 miles, seem to be dictated by especially complex synergies. For example, the maximum distance recorded for a Waste Electrical and Electronic Equipment (WEEE) synergy (171 miles) involved the initial long distance movement of the material for disassembly prior to moving back to within several miles of its donor symbiont for reuse. Again, the maximum resource movement distance measured for the Minerals category (259 miles) was almost certainly influenced by the fact that the origin symbiont is based in an outlying area of Wales; a country that does not possess hazardous waste disposal facilities. Bearing in mind that in industrial ecosystems high toxicity materials often move long distances for recycling (Hardy and Graedel, 2002), it is, again, perhaps surprising that instances of long distance hazardous material movement within NISP synergies can be seen to be unusual. The question thus arises, what is dictating the distances involved in NISP facilitated synergies?

Table 1 Resource movement distances (miles):

	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
Coatings	0.7	2.2	5.4	18.3	72.7
WEEE	0.4	7.7	11.4	24.5	171.1
Infrastructure	0.5	11.2	11.8	44.5	199.0
Glass	6.5	10.4	18.6	28.1	47.3
Paper & Cardboard	0.3	12.3	20.5	35.4	269.2
Foodstuffs inc. Oils	0.5	9.9	17.6	35.0	126.2
Compost & Soils	0.6	8.8	17.8	26.7	86.3
Minerals	0.3	9.4	18.1	35.5	259.7
Organic Chemicals	3.6	8.6	18.8	36.6	137.2
Wood Products	0.1	6.7	18.1	28.2	105.6
Composite Packaging	0.7	6.0	18.3	29.2	137.5
Misc. Plastics	0.2	11.7	20.4	32.5	173.3
Metals	0.5	9.2	31.0	67.1	242.4
Ashes & Slags	2.7	11.4	25.9	46.9	61.5
Fuels ^a	4.1	18.4	34.4	45.6	55.0
Aqueous Sludge	16.7	29.4	36.9	67.0	124.2
Textiles	0.9	15.6	44.5	78.4	201.0
Inorganic Chemicals	9.4	28.7	52.2	116.7	139.1
Rubber	7.5	26.1	62.0	84.4	129.9
Hazardous Wastes ^b	0.7	9.0	26.0	60.8	259.7
All Resources	0.1	9.6	20.4	39.1	269.2

Note: resource grouping and Table 1 stream titles are derived from NISP's bespoke waste stream categories. ^a The Fuels stream title refers to resources that are known to have been used in power production. ^b Hazardous waste movement figures derive collectively from synergies that claimed hazardous waste diversion outputs.

Figure 4: Box Plots of Resource Movement Statistics Indicating Minimum, Lower Quartile, Median, Upper Quartile and Maximum Values

3.2 Influences on Resource Movement

To determine what is dictating the relatively short distances that resources are moving there are several variables that can be analysed. With one of NISP's primary remits being the reduction of industrial carbon emissions, one obvious variable to consider would be how

much CO₂e emissions resulting from the transport of materials negate any savings derived from the reuse of a given material (and thus restrict how far materials can/should move).

However, for the vast majority of analysed synergies, CO₂e savings resulting from the establishment of a synergy were found to far outweigh emissions generated through haulage. Thus, an in-depth analysis of possible environmental restrictions (in the form of CO₂e savings/emissions) to material movement is not presented within this article. Based on several assumptions made on haulage method and the fuel efficiency of the vehicle employed (resulting in a vehicle emission factor of 1.01kg of CO₂e per road mile), the median of CO₂e emitted was calculated to be 0.026 tonnes⁹ (the mean being 0.039 tonnes). In comparison, median CO₂e savings per synergy were shown to be 51 tonnes (mean savings per synergy were shown to be 3,508 tonnes). Herein, five further resource movement influences have been considered:

- Logistic difficulties: are resource movements restricted due to physical difficulties involved in transporting heavy or irregular loads?
- Economic value: are resource movements restricted by the potential financial benefits of a synergy?
- Mental distance: is an inability to generate long distance intercompany trust restricting resource movement?
- Local knowledge: does practitioner knowledge of local industrial geography dictate symbiosis decision making?
- Diversity of UK industry: does relative industrial diversity affect resource movement?

3.2.1 Logistic Difficulties

One variable influencing the distances resources are moving within the presented synergies could be transport difficulties. For example, transportation difficulties could arise from abnormal or unusually heavy materials not being able to physically or financially travel long distances. For this hypothesis to be correct, one would perhaps expect a correlation to exist between the quantity of materials being exchanged within synergies and the distance materials are moving. However, within Figure 5, which presents a plot of the amount of material diverted from landfill (the indicator reported for the quantity of material involved in

⁹ One metric tonne (10³ kg) = 0.9842 imperial long ton or 1.1023 imperial short ton.

a synergy) against the distance a material moves, it can be seen that there is no relationship between material quantity and distance travelled. When subsets of the data employed within Figure 5 were examined to determine what is happening throughout the entire dataset, there was still no correlation between the mass of a resource and the distance travelled to the resource recipient. Furthermore, to the best knowledge of NISP practitioners, no resource movements have ever been restricted due to irregular haulage requirements (H. Hitchman, Pers. Comms., 2010). It seems that it can be confidently stated that, as a general rule, the physical characteristics of resources have not restricted symbiotic resource movement.

Figure 5: Quantity of Resource Plotted Against Resource Movement Distances

Note: since CRISP will allow the input of quantity data in several formats, including ‘Number of Items’, recorded landfill diversion outputs (in tonnes) were employed as a proxy to determine overall resource quantities. Due to the presence of clear outliers (discussed in Section 3.1), and to improve the clarity of the graphs, data points beyond the upper quartile (39.1 miles) are not shown. The correlation coefficient for all data points is -0.04; the coefficient excluding outlying data beyond the upper quartile is -0.03, i.e. no relationship exists between material quantity and distance travelled.

3.2.2 *Economic Value of a Synergy*

A variable to consider in relation to resource movement influences is the monetary value of the synergy to one or both symbionts. As stated within the introduction of this article, it is readily accepted that high value materials should not be spatially constrained. Indeed, within a national symbiosis network, high value products could easily travel several hundreds of miles. However, referring to Figure 6, which presents the economic value of a synergy (indicated by either the cost savings and/or additional sales resulting from a synergy) plotted against the distance a material travelled, it can be seen that there is no link between the relative value of a completed synergy and the distance resources have moved.

As Figure 6 represents all synergies, it could be surmised that any correlation between synergy value and resource specific movements is being lost within the trends of materials that are better represented within the dataset. However, when synergy value was similarly plotted against individual resource stream distances, there was no appreciable correlation between the two variables as can be seen from the correlation coefficients shown in Table 2 (plots for individual streams not shown). The apparent lack of a relationship between resource value and the distances involved in material exchanges is surprising as it, arguably, contradicts accepted resource movement theory; particularly when it is again highlighted that NISP practitioners, in ensuring that resource reuse is maximised and associated funding targets are met, do not consciously restrict the locations where they look for recipient symbionts. Indeed, based on the fact that many companies engage with NISP on the basis that it is a business opportunity programme, it is fair to state that, whenever possible, practitioners will attempt to present members with financially attractive solutions to their resource management problems. Potentially, to increase the likelihood of a synergy taking place, opportunities for resource exchanges could thus be presented to member companies which involve the transport of materials over significant distances.

Figure 6: Economic Value of Each Synergy versus Resource Movement Distances

Note: economic value was determined via the recorded additional sales and/or cost savings resulting from a synergy. Data points beyond the upper quartile (39.1 miles) are not shown. The correlation coefficient for all data points is 0.03; the coefficient excluding outlying data beyond the upper quartile is 0.02, i.e. no relationship exists between the economic value of a synergy and the distance the material travelled.

Table 2 Correlation coefficients for economic value of resource specific synergies versus resource movement distances.

Category	r^a	UQr^b
Coatings	-0.04	-0.55
WEEE	0.21	0.16
Infrastructure	0.18	0.72
Glass	0.16	-0.32
Paper & Cardboard	0.04	0.32
Foodstuffs inc. Oils	0.06	0.06
Compost & Soils	-0.22	-0.26
Minerals	-0.09	0.11
Organic Chemicals	-0.01	0.23
Wood Products	0.21	0.16
Composite Packaging	-0.14	-0.14
Misc. Plastics	0.23	-0.08
Metals	-0.17	0.05
Ashes & Slags	0.14	-0.12
Fuels	0.13	0.60
Aqueous Sludge	-0.03	-0.11
Textiles	-0.13	-0.04
Inorganic Chemicals	-0.24	-0.07
Rubber	0.46	0.49
Hazardous Waste	0.01	0.39
All Resources	0.03	0.02

^a r shows correlation coefficients for all data observed within the given resource's dataset.

^b UQr shows the correlation coefficient excluding data points lying beyond each resource's upper quartile (see Table 1).

3.2.3 Mental Distance

Other than the physical properties and value of a synergy dictating the distances resources are moving within symbiotic exchanges, the other readily accepted variable that could be influencing resource movement is 'mental distance' restrictions. That is to say, the apparent industrial symbiosis phenomena of actors not being willing to work with companies that they do not have an existing professional or social relationship with is coming in to play. Although all resources are freely available for any practitioner to create a company to

resource match, regardless of their respective geographic locations, industrial symbiosis literature (see Section 1.2) suggests that the influence of mental distances would cause Programme members to be inclined to only work with people or companies that they can readily generate a trusting relationship with.

It could be argued, however, that within an independently coordinated industrial symbiosis programme, trust and short mental distances are not as influential, if at all, on the facilitation of synergies as is the case with happenstance organic symbiosis. Furthermore, within the NISP delivery model, synergy opportunities are primarily identified by practitioners and not companies. Once a company has made the effort to join the Programme the company has effectively bought-in to the idea of industrial symbiosis and potentially what it entails in relation to cooperation; particularly in regards to knowledge sharing. Additionally, it can be argued that the need for trust and short mental distances between symbionts is circumvented by the prospect of a sound business opportunity. Essentially a company's volition to share data and knowledge, and engage in the potential by-product exchanges presented to them, is down to the transparent and proven successful processes that NISP presents to industry. Due to the way the Programme operates, it is thus argued that trust oriented mental distances are not the primary factor dictating the short resource movement distances presented within this article.

3.2.4 Local Knowledge

Due to the increased number of actors it has been previously surmised that larger regional areas may be more suited to the implementation of industrial symbiosis (e.g. Sterr and Ott, 2004; van Berkel, 2006). However, it was also thought that larger geographic working areas could present significant challenges for industrial symbiosis: among other, it has been suggested that it could be difficult to establish sufficient levels of intercompany trust and coordination and, importantly, it could prove problematic to collect and homogenise the resource data required to enable the identification of prospective partners (Sterr and Ott, 2004). These concerns were said to be potentially addressed via the establishment of regional symbiosis coordination. At the time this suggestion was made, however, there was a lack of evidence to qualify whether regional coordination of industrial symbiosis would be successful (Sterr and Ott, 2004); arguably, this changed with the emergence of NISP and the availability of the first five years of operational data.

NISP delivery teams consist of people possessing a wide range of industrial knowledge and practical skills. More importantly, the personnel within the teams are typically natives of

the region they are assigned to and/or possess significant experience of working within that region. The collective knowledge of a given region's industrial geography, the pooling of a diverse range of skills and personal links into industry and academia, form the basis of a knowledge bank especially suited to the implementation of industrial symbiosis. When a company approaches a practitioner with a resource for potential symbiotic exchange, the practitioner typically possesses an immediate idea for resource reuse and has a company, or type of company, in mind to act as a prospective symbiont. If a given practitioner does not have an idea for the facilitation of a symbiotic agreement, another member of a given regional delivery team typically will have.

Although CRISP is a national inventory of all available resources and prospective symbionts, it never replaces a practitioners personal knowledge of a given resource or company. As and when local solutions are found by one region, they tend to translate to other regions. Thus, the CRISP system, which logs the facilitation details of all completed synergies, acts as a potential 'e-manual' for further regional industrial symbiosis implementation. Effectively diverse local industrial knowledge, logged into a national network, creates a reciprocal feedback system that sees one region's local successes being presented as potential industrial symbiosis best practice within another. Hence, resources typically move short distances within NISP facilitated synergies due to the national replication of local symbiosis best practice. It is thus argued that the distances presented within this article, despite being drawn from a national database, primarily reflect regional knowledge and the industrial geography of the UK (discussed next).

3.2.5 Geographic Industrial Diversity

It would seem that a practitioner's knowledge of local industrial geography, which returns the specific distances presented within Table 1 and Figure 4, is dictated by the relative diversity of the UK's industrial sector. As a mature industrialised country, areas of industrial activity can be found within most parts of the UK. Though some regions are particularly predisposed to a given industry, most possess a diverse mix, to varying extents, of industry types. Thus, it seems apparent that the 20.4 mile average distance that resources are moving is simply the limit of the effects of agglomeration. That is to say, within approximately 20 miles of resource origin, sufficient diversity of industry will typically exist that will allow the discovery of an unrelated potential resource recipient.

Interestingly, the 20.4 mile average resource movement figure compares well with the TEDA cross boundary resource movement figure of 34 km (approximately 21.2 miles). If the

similarity between these figures is not solely coincidence, and with further research it can be deemed a general rule of industrial symbiosis that synergies tend to be facilitated within an approximate 20 mile radius of resource origin, a figure has been attained for the active development of regional industrial ecosystems¹⁰. Along with the presented resource specific data, 20.4 miles is also a figure that industrial symbiosis delivery bodies can use to optimise their working operations in a multitude of ways; ranging from the simple cost effective deployment of practitioners, to the application of strategic industrial symbiosis facilitation, via, among other, GIS multi-criteria resource mapping.

4. Conclusion

Over a period of approximately five years, NISP has consistently identified and successfully implemented resource synergies between a myriad of industrial sectors, of which half were facilitated within a 20.4 mile geographic radius and three-quarters within a 39.1 mile geographic radius of resource origin respectively.

It is argued that key to NISP's success is national access to transferable local knowledge of industry and the willingness of companies to engage in a business opportunity programme. Importantly, by being an externally funded independent body with clearly visible processes, the need for absolute trust in another company is, at least initially, by-passed. Programme members (that is to say, companies) do not have to nurture short mental distances or concern themselves with geographic proximity because a practitioner, working on their behalf, is typically able to identify a win-win local solution that is at least as attractive (typically from a financial and practical point of view) as any likely to be offered by a solution provider many miles away. If and when necessary, however, the presented resource movement data shows that a nationally networked model of regional industrial symbiosis delivery is perfectly capable of facilitating both financially and environmentally sound synergies over significant distances.

Arguably we do not need to nurture *opportunities* for industrial symbiosis: economic and environmental forces will inherently continue to provide opportunities for eco-industrial development. Evidence presented within this article suggests that an independent national coordinator can act as the embodiment of industrial cooperation that is ideally placed to collect and synthesise operational industrial knowledge into identified opportunities for

¹⁰ Within industrial symbiosis literature it has been previously asked what would be an appropriate scale for the implementation of eco-industrial development (see Gibbs, 2008, and associated references).

regional resource efficiency. The distances involved in ascertaining relative geographic proximity will eventually reveal themselves as a national knowledge network reciprocally delivers local industrial symbiosis. From the presented analysis of NISP facilitated synergies, it can be stated that, within the United Kingdom, the spatial distribution of industrial diversity dictates 'geographic proximity' to be 20.4 miles. Though further investigation and confirmation is clearly required, it is anticipated that the presented results and discussion may well be applicable to other similarly industrialised countries as the United Kingdom.

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