

# **Innovation Processes in the Manufacturing Industry Modelling Trajectories and Social Networks within GIS**

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## **Abstract**

This research aims at better understanding the diversity of factors conditioning access to resources during the innovation process in the manufacturing industry of non-metropolitan regions putting emphasis on both the societal and economic aspects of the innovation process trajectory, studying the functioning of the host firm from a spatial and temporal perspective. Based on in-depth surveys realised within selected firms, trajectories of innovation (either developing a new product or an improved manufacturing process) are detailed to identify actors involved in the process, discover their relationships and study social networks leading to success or failure. All actions are facts recorded in a geographical information system database describing linkage and cooperation among persons, firms and institutions to define social networks. The objective of this paper is to discuss methodological issues for encoding dynamics of innovation processes using temporal GIS technology to organise facts reported by firms' top managers during the survey. In this first stage of the project, the actual implementation is using ER model to record and to structure information gathered among managers telling us the history of their innovation processes. User interface were built into database software in order to navigate within complex sets of actions, actors and social networks. In the long term, this research aims at analysing innovation paths and discover factors leading to (or delaying) success of innovation using event history analysis (Cox regression) to relate the overall process to trajectories made of specific actions and the structure of social networks defining qualitative attributes of the manufacturing milieu, and thus, making inference from the sample (testing hypotheses).

**Keywords:** Innovation trajectories, geographical information system, event history modelling, social networks.

## **1. INTRODUCTION**

Studying the spatial dynamics of economic activities raises issues on accessibility to material and societal resources needed to develop regions. In a recent paper, Polèse & Shearmur (2006) present the factors they associate with the decline of five Canadian peripheral regions in the context of globalization: population aging and decline, remoteness to markets, industrial structure based on primary resources, high wages, etc.). Conversely, they argue that an efficient institutional setting, a positive social climate and an industrial mix operating in local environment conducive to cooperation are prerequisite for innovation. Most of the factors they identify are rather classical and relate to centre-periphery differences and effects of agglomeration. They argue that more complex sociological-institutional explanations (entrepreneurship, social capital, innovative milieus, learning networks) could be as important for explaining regional decline or success.

This research aims at better understanding factors conditioning access to resources during the innovation process in the manufacturing industry, making the comparison between metropolitan and peripheral regions. It puts emphasis on societal and economic aspects intertwined in the innovation trajectory, studying the functioning of the host firm using a spatial and temporal perspective. Based on in-depth surveys realised within selected firms, trajectories of innovation (either developing a new product or an improved manufacturing process) are detailed to identify partners involved in the process, discover their relationships and build social networks leading to success or failure. Success is

granted when the new (improved) goods are exported; failure occurs when the firm gives up the process. Each trajectory is made of a succession of actions located in both time and space. Each action can occur within the firm or outside its facilities. All actions are facts recorded in a GIS describing linkage and cooperation among persons, firms and institutions to define social networks.

The main objectives of our research are: (1) to record the dynamics of innovation processes using TGIS (temporal GIS) to organise facts reported by firms' managers during a retrospective survey; (2) to observe, describe and analyse the making of innovation-support institutions through trajectories as reported by business persons; (3) using a multi-disciplinary approach, to analyse the multiple aspects (social, technical, economic, ...) pertaining to accessibility to resources needed for firms' development, considering the ordering of facts within the innovation trajectory. This paper reports on preliminary findings linked to the first objective of this research project.

Section 2 presents an overview of the current state of the art in the problem area: modelling the impact of innovation and social networking in the success of manufacturing enterprises. Section 3 tackles some specific issues related to the structuring of information obtained during our retrospective survey and makes some linkage with literature in TGIS. Section 4 describes choices made for the actual implementation using relational database technology in conjunction with desktop mapping. Finally, last section discusses preliminary results and concludes the paper with an agenda of what should be done in the next steps in order to test hypotheses about the impact of social network on the innovation trajectory.

## 2. CONTEXT OVERVIEW

Literature dealing with innovation, entrepreneurship and regional development generally focuses on few seminal topics. Research on small and medium-size fast-growing enterprises (SME) is replete of examples which target main factors responsible for growth of firms: mainly innovation, partnerships, quality of management and impact of governmental agencies for the financing (or the subsidising) of growth.

Johannison *et al.* (2002) define three level of embeddedness (being anchored in a larger structure) of relationships in the networking of enterprises. Embeddedness is relevant for studying firm's performance because "economic action is affected by actor's dyadic relationships and by the structure of the overall network of relations" (Granovetter 1992: 33). Johannison *et al.* (2002) explain how it contributes to the anchoring of firms in the local community: being part of extended business networks provides a wide range of opportunities and constrains acting as leverage for business creation. They distinguish among: (1) the immediate surrounding of the firm defining the egocentric network; (2) the institutional surrounding defining a sociocentric network; and (3) the global network which is accessed sporadically. Networks are forms of voluntary co-operation for sharing information, mutual learning and exchanging among members. Moreover, they also involve social control which could impede some innovation or, conversely, would enforce trust-building processes.

According to Uzzi (1997: 35), "research on embeddedness is an exciting area in sociology and economics because it advances our understanding of how sociological structure affects economic life". Using ethnographic fieldwork, he proposes a framework to relate firm's strength with the quality of social ties, the structure of the organization network and its position in the network. Empirical research on firm competitiveness has shown an association between networking, activity and growth of firms. Lechner & Dowling (2003) studied egocentric networks of high-growth firms in the information technology industry and explored how these firms actually grow using external relations. Growth is path-dependent and the relational capability of firms eventually reaches its limits leading to stable networks. Therefore, understanding innovation process implies considering the whole trajectory (ordered set of facts and events). More importantly, firm growth depends on both the egocentric networks based on strong ties and the setting-up of healthy sociocentric networks providing weak ties.

Hansen (1999) was making comparison of the effects of weak and strong ties on the success (and duration) of innovation processes. Analysing the trajectory of 140 new-product development projects undertaken by a large electronic company, he finds that “weak inter-unit ties help a project team to find useful knowledge in other subunits, but impede the transfer of complex knowledge, which tends to require a strong tie between the two parties” to occur (Hansen 1999: 82). Moreover, the time it takes for the process to deliver outcomes is related to the strength of ties, weak ties speeding up the project. But are those findings general? Are they scalable and still valid for SME?

Most studies dealing with innovation at the firm level are based on in-depth surveys of a very small set of enterprises, and researchers rely on their judgement for interpretation of facts and ranking factors. Drawbacks of this approach are: (1) problem to distinguish among intertwined factors; (2) set of facts should be synthesized because there is no mechanism to handle complexity; and (3) difficulty to generalise beyond the actual sample because there is no way to test hypotheses. Is there some existing robust statistical method geared to analyse complex trajectories of events leading to some expected result?

Yes it does. Depending on application sectors, it is called robustness analysis or event history analysis (EHA). Both techniques are based on the Cox regression which makes a combination of survival tables and logistic regression. Blossfeld & Rohwer (1995) present fundamentals of the Cox regression and several examples for the application of event history analysis. EHA provides two kinds of results: (1) a survival curve which relates an expected event (e.g. death) with elapsed time after a specified starting point (e.g. birth); (2) for each factor which is allegedly marginally responsible for the event to occur, it computes an odds ratio and the probability that the observed results may come by chance only (significance).

Park & Russo (1996) are using EHA for analysing trajectories leading to failure of joint venture in the electronics industry from 1979 to 1988. Joint ventures are complex processes involving balance between competition and cooperation. EHA was used to test significance of specific hypotheses (e.g. *A joint venture between direct competitors is more likely to fail than one in which the partners do not compete*) and to estimate their survival rate after the agreement was signed. Cefis & Marsili (2005) examine the effect of innovation on firm survival using data on all manufacturing firms active in the Netherlands and responding to the Second Community Innovation Survey for the period 1996-2003. Using Cox regression, they estimate models of life expectancy taking into consideration innovation, innovation type, firm size, age, growth and industrial sector.

### 3. METHODOLOGICAL ISSUES

Describing innovation trajectories while keeping track of every significant fact (action or event), identifying every participant (person, firm, partner, customer,...) needed to define social networks, the enterprise's environment and the management is a complex task. It becomes more complex because we rely entirely on the recall of events by a selected manager responding to a retrospective survey. The interview has a limited duration of two hours and is voice-recorded for later reference. Top managers voluntary – and freely – gave time to our project. To be efficient at filling a data table with hard coded attributes (true/false, categories, or numerical figures) needed for statistical analysis based on a structured interview, we asked the respondent to tell us the history of two innovation processes carried out in his/her enterprise during the last ten years, one which was successful (profits were made), one which was failing (non profitable). In order to obtain all information we designed a questionnaire showing exactly the data which are needed for modelling, and what level of detail is needed. It can be used directly to record static information about the firm and its operational context. However, doing preliminary tests, we soon discovered that the questionnaire was impracticable for gathering information about the innovation processes, mainly because they are multidimensional sets of facts, defining lots of intertwined social (actors involved) and temporal (ordered sets of actions and events) networks. Using a database oriented structure (recording event, actors, actions, locations, time

periods, etc.) or any hierarchical order to obtain facts was highly detrimental to the flow of discourse of the respondent. Even using efficient user interface, it was impracticable to enter the information into the database in-site without disturbing the interview. Thus, we built a checklist for every attributes needed for any piece of data to be complete. During the interview it is used to double check completeness of the history, delaying the gathering of data into the database.

The questionnaire has three sections. The first one is classical and describes mostly “static facts” related to the respondent and its education, the enterprise, location, sectors of activities, legal status, quality norms, employees and their qualification. The second part forms temporal networks recording, for each innovation process, ordered facts (actions), any involved participant (actors) and groups of actors jointly involved in several actions. Each actor provides a location while the action has duration and a time span. Depending on the precision of information recall, we have to manage fuzziness on location (spatial granularity) or time-duration (temporal granularity). Qualifiers complement the recording of any spatial and temporal attribute. In order to ensure means for analysing networks based on geographical location, we designed a unique repository to keep track of every locations reported by all respondents, providing a world-wide list of locations with an application-based and explicitly specified level of granularity. Finally, the third part is about social networks and relates the actors involved during innovations (most are members of egocentric networks) to the other components of sociocentric and global networks, defining nodes on those networks graphs which are located in space, have a duration (time period) and a frequency of interaction qualified using a respondent-specified periodicity (weekly, monthly,...). Then, the problem arises on how we could implement and operate such a complex data system within a TGIS.

Diffusion of innovation is a classical topic in economic geography. In the fifties, the Swedish geographer Hägerstrand (1953) was developing theories on the constraint space puts on diffusion of innovations, leading to observable geographical patterns. Using empirical data on the adoption of innovations, geographers were able to model the spatial structure of those patterns and relate them to average local socio-economic attributes, during the seventies and the eighties. Unfortunately, the lack of information about the innovation process itself impedes them going farther, until recently. But, even if there is always a spatial component tacked up to innovation and its diffusion, one would admit that other dimensions (mostly temporal and societal) are relevant and should be included in the analysis, which implies designing an appropriate spatio-temporal and thematic data structure.

The information triad proposed by Peuquet (2002) could record in the same data structure information related to the three “W” of any well designed news (“What?”, “When?” and “Where?”). Unfortunately, in this application facts are not independent pieces of information, but they define multi-level networks of relationships that should be explicit in order to convey the history behind the trajectory and the social networks. Therefore, the triad is useful but not sufficient. A complementary way to address issues would be to use object-oriented (OO) DB technologies to model transformation of entities, using approaches similar to those presented by Wachowicz (1999) or Hornsby & Egenhofer (2000). Again, there is a fundamental issue. We are not trying to model changes on entities of the real world (like parcels’ shapes and ownership in a cadastre) but a succession of immaterial actions involving several actors forming short-lived sets of persons and institutions embedded within egocentric and sociocentric networks. However, although the actions are delimited by time periods, they actually gain materiality (and multiple locations in space) when related to actors. The structural, spatial and temporal evolution of those networks should be reflected in the DB, on top of the actual facts reported by the respondent. In fact, they are indirect triggers/consequences of innovation trajectories and the data structure should be able to draw their evolution using deductive approach.

According to Worboys (2001: 132), an event is a “key notion in the modelling of dynamic systems. A dictionary definition is ‘a happening, occurrence or episode’”. He presents various alternatives to model change and events in dynamic systems. It is clear from a conceptual point of view that the ER model is mostly static and has the limitation that only entities, attributes and

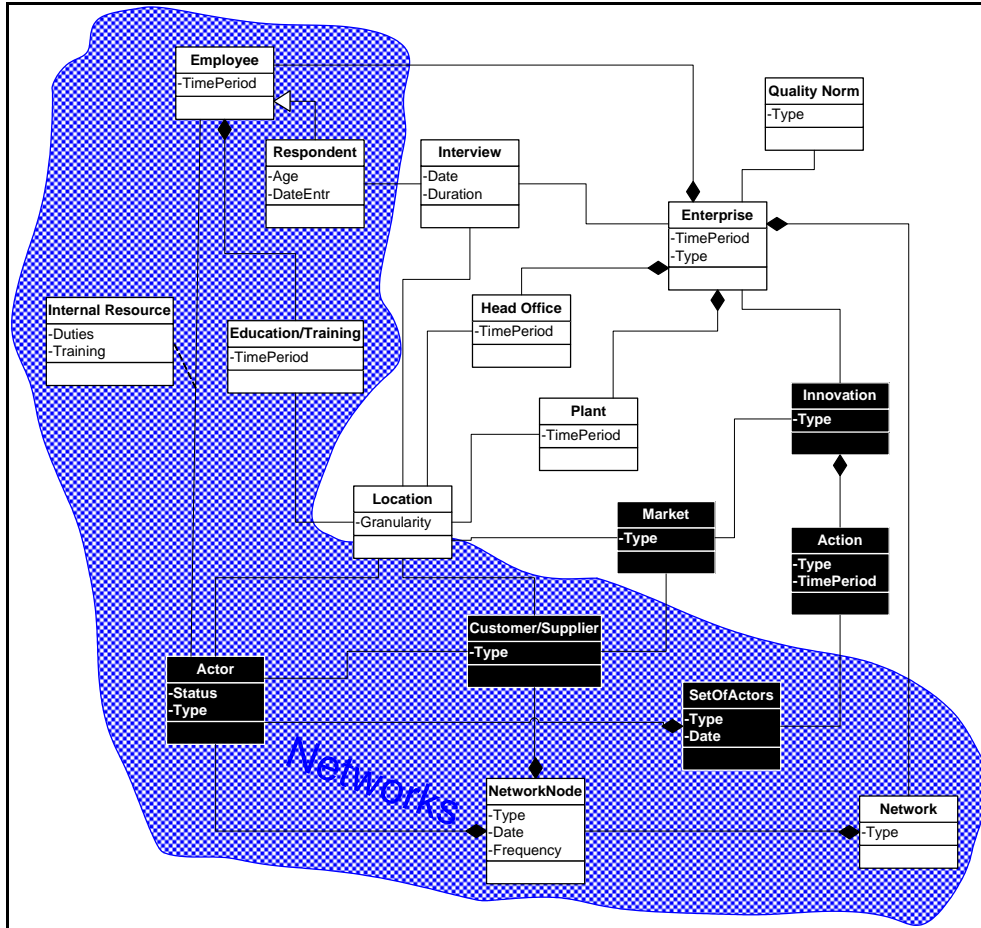
relationships are provided as primitive constructs. "Thus ER will only be successful if events can be considered as entities or relationships." (Worboys 2001: 132). To achieve efficiency in modelling such a dynamic system, OO provides more constructs, especially if design is done using the unified modelling language (UML). Moreover, even using sophisticated modelling tools, one will eventually face problems when trying to query the database using SQL to the level it is actually implemented within DB and GIS software packages. Worboys (1997) discusses development of new query languages providing improved handling of temporal relationships, like TQUEL, SQL-92, TSQL2 (Snodgrass *et al.* 1994) and SQL3. All these innovations are certainly very good news and provide strong bases for furthering TGIS. But, from an end-user standpoint, implementing a system based on these innovations would imply substantial in-house development because such functionalities are not available in standard DB and GIS packages. Our project has limited budget, should be realised in about three years and must put its money on analysing innovation and collecting data to build models and tests hypotheses using a novel approach. The structuring of the TGIS platform is important, but instrumental.

#### 4. IMPLEMENTATION

Needing to be pragmatic, we decided to build on a former experiment which was relevant to implement TGIS for handling trajectories using the lifeline metaphor (Thériault *et al.* 2002). It was efficient to model intertwined trajectories depicting events occurring during the active life of professionals and was sufficient (although not optimal) to query complex data structures in order to actually develop event history regression models. There is lot of work still remaining beyond what is actually done in this first stage of our project. However, describing our actual implementation has at least two interests: (1) it provides an empirical assessment of what could be done to model innovation trajectories using ER models (our system actually works to record and structure data); and (2) it gives ample opportunity to experiment with real day-to-day tasks and identify weaknesses and improvements needed to generalize such a type of application within TGIS.

Figure 1 depicts the application domain using UML. It is using classes to encapsulate basic facts recorded during the interview. Innovation trajectories and social networks are higher-level constructs which can be defined using networks of relationships (e.g. binary association, composition, generalization, association classes) among sets of classes. Obviously, UML offers the expressiveness to define such an application comprehensively, providing activity, sequence, state chart and use case diagrams on top of the static view presented in Figure 1. However, depending on the immediate goals of our project and its context of operation (little resource for programming and using low-cost DB environment), we decided to restrict ourselves to the ER model in order to implement a tiny system involving a conjunction of Microsoft Access linked to a standard GIS package using DB management service (DBMS) like ODBC (On-line DB connectivity).

Figure 2 shows a view over the actual data gathering interface. It provides a hierarchical interface to access dynamic tools aimed at managing actual sets of actors, ordered sets of actions and network nodes. Integrity constraints are specified in the model and enforced. The interface is complex and divided in sub-sections giving access to individual parts of the questionnaire. Each sub-section provides interfaces, eventually leading to the inclusion of several tuples to describe a set or an ordered set of facts (e.g. events, actions, actors), and controls to further define complex relationships like linkage among persons.



**Figure 1:** Simplified UML static diagram of the application domain.  
 Classes with black background form the innovation trajectories; networks are outlined.

The information gathering process is ongoing. Doing the interview and entering the data is a long and tedious task which is somewhat simplified, and most importantly supervised, by the DB constraints and the interface. Thus, we have confidence that resulting data will be suitable for statistical analysis. However, we took care not to over-simplify lists of categories during the data gathering process, leaving opportunities to test various taxonomic schemes when calibrating statistical models. Figure 3 gives an example of such extended categorization for the types of actors involved in the first fourteen innovation processes entered into the BD. It took about ten minutes to map the actual base location of all actors involved in the fourteen innovation processes. Figure 3 shows a zoom over North America. For building such a static spatial view, the operations are quite simple. Spatio-temporal and network-oriented queries will require more sophisticated languages to define queries.

The screenshot shows a web-based data gathering form titled "Formulaire Principal : Innovation, entrepreneuriat et territoire". The form is divided into several sections: "Entreprise", "Innovations", and "Action".

**Entreprise Section:**

- No.Entreprise:** 1
- Nom Entreprise:** Equipements Tremzac
- Statut légal:** Société incorporée
- Localité Actuel:** Saint-Bonaventure (Ville), Québec
- Intensité techno:** Moyenne-haute technologie
- Croissance (%/San):** 33 (An1: 1, An2: 2, An3: 3, An4: 4, An5: 2)
- Région (MRC):** Drummond
- Chiffre Aff:** 5,5; **% ChiffAff RetD:** 8,6
- Exportation?** ; **% Exportation p/r ChAff:**
- Parc Industriel?**
- Nb Employés:** 30; **Nb Cadres:** 5
- Zone administrative? (Urban [x] / Rural [ ]):**
- Mois Fondation:** janvier
- Année Fondation:** 1986
- Nb Ingenieurs:** 2; **Nb Techniciens:** 1
- Localité Fondation:** Saint-Bonaventure (Ville), Québec

**Innovations Section:**

- Nb Innovations/10ans:** 85; **% Innov.Reussi:** ; **% Innov. p/r Produits:** 25; **% Innov. p/r Procédés:** 75
- No.Innova:** 1; **Processus:** Création d'un nouveau produit
- Innovation:** Empileuse à bois
- Propre Initiative?** ; **Nouv.secteurAct.?**
- Nouv. Brevet?** ; **Achat Licence?**
- Rentable?** ; **% Rentabilité:** 8
- Dévelop.nouv.marché?** ; **Echec Techniq?** ; **AutoFinancement?**
- No.March (Auto):** ; **Marché:**
- Ordre Chrono:** ; **% Chiff. Aff.:**
- Enr:** 1 sur 1

**Action Section:**

- Action description:** Commande client
- No.Action:** 1
- Catégorie:** Commerciale (Commande client)
- Chronologie:** 1
- MoisDebut:** janvier; **MoisFin:** février
- AnnéeDebut:** 2003; **AnnéeFin:** 2003
- TempoDebut:** Mois; **TempoFin:** Mois
- Localité:** Saint-Bonaventure (Ville), Québec
- Censure?**
- Définir la liste des Intervenants pour cette action:**
- Enr:** 1 sur 10
- Enr:** 1 sur 2
- Enr:** 1 sur 13

Figure 2: Example of data gathering forms: Innovation, entrepreneurship and territory.

Obviously, searching within sets, following paths along the innovation trajectories and analysing the social networks imply sophisticated approaches. However, building on former work (Thériault *et al.* 2002), using DB technology in conjunction with proprietary software development within a GIS to build plug-in applications, we reasonably expect, at a later stage, to ease the very complex task of transforming data as it is coded after the interview into a flat table which is needed to do statistical analysis (using statistical software like SPSS, Stata, SPlus), reshuffling information along the time line and within networks. The social networks are themselves subjects of investigation. There are some basic rules on what components each network should include. But, there is ample room for analysing network structure's modification when changing what is actually considered in each part of the network. Network analysis software (like UCINET) developed for social science applications could provide high level attributes describing networks' structure for their inclusion in the Cox regression modelling procedure.

## 5. CONCLUSION

To the best of our knowledge, this research is the first attempt to model and analyze innovation paths within TGIS. From a theoretical standpoint, the ER model is probably not the most efficient

approach to solve our problem. But, it actually works and permits timely development of our application with limited resources and within a time frame which is compatible with our research agenda. However, the complexity of such an application and the diversity of issues it triggers for providing efficient and generic solutions within GIS provide lot of inspiration for improving methodological research on designing TGIS which can handle facts related to immaterial features.

Future additions which could be highly desirable are: (1) hierarchical reasoning capabilities (Claramunt & Jiang 2000) to enhance navigation and queries using temporal and spatial granularities; (2) deductive database features like those presented by Worboys (1997: 323) to define (and re-define) social networks based on evolving criteria; and (3) efficient mechanisms to navigate along the time line (to follow tracks on the innovation trajectory) and to express spatio-temporal queries considering linkages with and among associated actors, multiple locations, relationships among time periods, time/space granularities, etc.

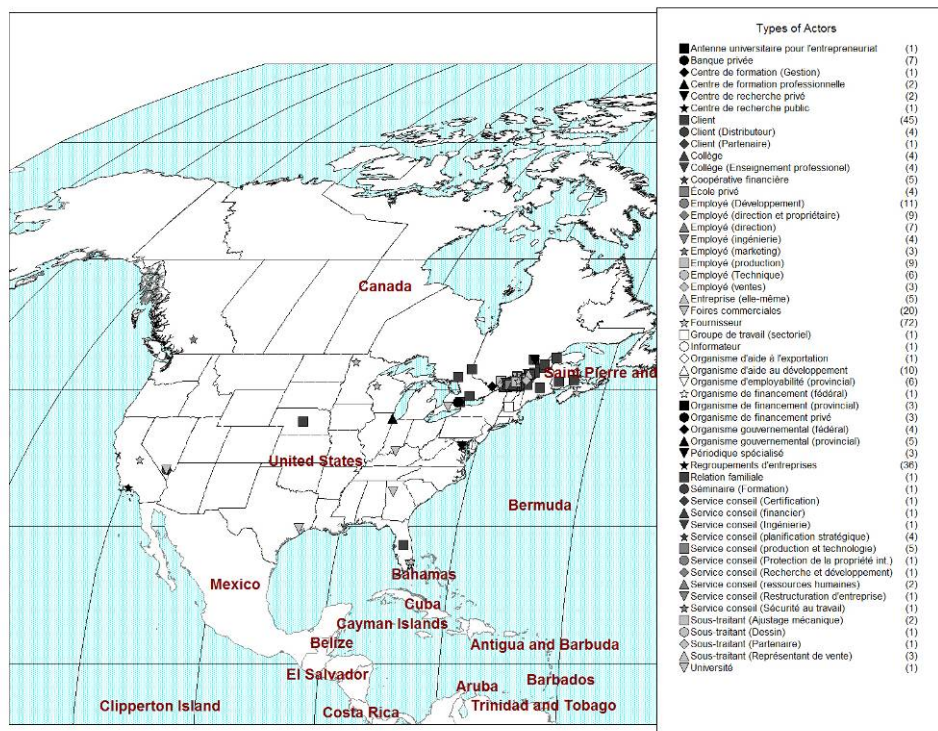


Figure 3: Distribution of actors involved in 14 innovation trajectories within Drummondville firms.

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