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FACULTAD DE INFORMÁTICA
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MODELLING HUMAN BAHAVIOUR AT WORK: AN AGENT-BASED SIMULATION TO SOPPORT THE CONFIGURATION OF WORK TEAMS.

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TESIS DOCTORAL

Herramienta de Simulación Basada en Agentes para la Ayuda en la Formación y Configuración de Equipos de Trabajo

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Dedicated to Marta and Daniel,
who are my sources of motivation and inspiration.

ABSTRACT

The modelling and implementation of human behaviour into artificial systems have attracted the interest of several people from different disciplines given the *natural* complexity and multidisciplinary of this phenomenon. This type of models offers a great potential in a large set of domains including military applications, training and learning, e-health, and the representation of crisis and emergency situations among others. A particular interesting application is the modelling of human behaviour within groups. More specifically, the model of human behaviour in a work team would be used to analyse the specific dynamics behind individual and work team performance. The analysis of these dynamics then can be used as additional and useful information that supports the decision-making in the formation and configuration of real work teams in companies.

The work described in this thesis presents a novel agent-based simulation model that aims to support this decision-making process. This global objective is achieved through the modelling of the team candidates as software agents forming a virtual team. The configured virtual team then can be used to experiment with the internal and contextual factors that produce and direct the individual and work team performance. The real team candidates are modelled through a set of selected human characteristics that have been proved to influence human behaviour when making work activities in a work team. These characteristics include *cognitive capabilities*, *emotional state*, *personality styles* and *social-related skills*. Using the values in these attributes in combination with values represented in the attributes of project's tasks, the model produces statistical information that represents the possible performance of the team-members over the assigned project.

The theoretical background of the model is presented through a deep review of existing (mainly psychological, sociological and organisational) theories focused in the study of human behaviour within the particular context of teams. The work presented in this thesis uses the findings from this theoretical research to implement the main characteristics of the proposed agent-based model and to further develop a usable software simulation tool. This tool has been used to validate the proposed model through the comparison of the work team's performance results generated by the simulation tool against the performance evaluation results of a real work team from a large company. The validation results and the identified open issues to improve the model are also presented in the final part of this thesis document.

RESUMEN

Introducción

El modelado, representación e implementación de comportamientos humanos en sistemas artificiales ha atraído el interés desde hace ya varios años de un gran número de investigadores pertenecientes a diferentes disciplinas. Sin embargo, el desarrollar un adecuado y completo modelo del comportamiento humano es altamente complicado dada la entidad a modelar: los humanos son *inestables*, impredecibles y autónomos por naturaleza. El comportamiento de un individuo variará no sólo a partir de factores tales como la cultura, educación y experiencias vividas, sino también a partir de sus estados fisiológicos y psicológicos. Debido a estas características tan particulares, los humanos no pueden ser modelados como simples máquinas en una cadena de producción. Afortunadamente, en los últimos años, nuevas técnicas han sido desarrolladas (principalmente aplicadas a dominios militares y de ciencias sociales) con las cuales es válido decir que el modelado del comportamiento humano en contextos específicos es posible.

Este tipo de modelos proporcionan un gran potencial al desarrollo de simulaciones computacionales en diferentes y muy variados dominios donde intervienen equipos humanos, tales como las aplicaciones militares, la ayuda al entrenamiento y aprendizaje, o la gestión de situaciones de emergencia, entre algunos otros. Una aplicación particularmente interesante de este tipo de modelos es el modelado del comportamiento humano dentro de un grupo. Más específicamente, el modelado y simulación del comportamiento humano dentro de un equipo de trabajo ayudaría a analizar y entender mejor las dinámicas que producen y afectan el desempeño tanto a nivel individual como a nivel colectivo. La identificación y análisis de estas dinámicas sería una ayuda importante durante la toma de decisión relacionada a la formación y configuración de equipos de trabajo en contextos empresariales e industriales.

El formar un buen equipo de trabajo no depende únicamente de las habilidades cognitivas de los integrantes, sino también depende directamente de algunas características personales tales como habilidades sociales y tipos de personalidad. Estas características ayudan enormemente a crear un buen ambiente de trabajo entre los participantes facilitando una buena comunicación, cooperación y colaboración entre los miembros del equipo, aspectos que son fundamentales para el éxito final en el funcionamiento del equipo. Además de las habilidades sociales y de los distintos tipos

de personalidad, el estado emocional de una persona juega un papel determinante en la toma de decisiones, percepción del entorno en el que se encuentra, así como de la interacción con los demás, afectando el desempeño diario de una persona durante toda la existencia del equipo de trabajo.

Idealmente, aunque no usualmente, cada administrador de proyectos responsable de la formación y configuración de equipos de trabajo debería contar con información verídica y actualizada sobre el perfil personal y profesional de cada uno de los posibles candidatos. Afortunadamente en la actualidad existen varios *tests* dentro del área de Recursos Humanos para obtener información sobre determinados factores humanos que son importantes a tener en consideración al formar un equipo de personas. Estas pruebas incluyen desde los *tests clásicos* para obtener el coeficiente intelectual de una persona, hasta pruebas para obtener información sobre características psicológicas tales como de inteligencia emocional, personalidad, habilidades de comunicación, etc. (diferentes tipos de pruebas pueden encontrarse fácilmente en internet, ver por ejemplo: http://www.queendom.com/tests/index.html). La información obtenida de este tipo de pruebas puede ser bastante útil para conocer en más detalle las características personales y profesionales de cada candidato y puede ser utilizada como una ayuda adicional en la integración y formación de equipos de trabajo.

Sin embargo, en la mayoría de los casos, la información obtenida de los *tests* anteriormente mencionados no es suficiente para intuir cuál podría ser el posible desempeño como equipo de estas personas en el momento de estar interactuando conjuntamente frente a un determinado conjunto de tareas. La información obtenida de los *tests* individuales sería mucho más útil para cualquier líder de proyecto si pudiera ser utilizada para construir *equipos virtuales* de trabajo que representaran las características individuales de cada uno de los candidatos reales y realizar simulaciones para analizar el posible comportamiento de cada persona frente a las tareas que le han sido asignadas y cómo sería la interacción con el resto del equipo durante la duración del proyecto.

El trabajo desarrollado en esta tesis doctoral presenta un nuevo modelo de simulación basado en agentes para ayudar en la configuración y formación de equipos de trabajo. Este modelo representa a los candidatos reales a formar el equipo a través de agentes de software, los cuales integran un equipo *virtual* que puede utilizarse para experimentar con los factores internos y contextuales que afectan el comportamiento y desempeño individual y colectivo. Cada candidato real es modelado a partir de un conjunto de características *cognitivas*, *sociales*, *emocionales* y de *personalidad* para simular el comportamiento y desempeño de un equipo de trabajo frente al conjunto de tareas que tienen asignadas. En particular, el trabajo descrito en este documento modela y simula el comportamiento colectivo en un equipo de trabajo a partir de la interacción individual entre los miembros del equipo, utilizando las características individuales ya mencionadas, y un conjunto de características que representan el proyecto que deben desarrollar.

El modelo de simulación basado en agentes descrito en esta tesis permitirá a un administrador de proyecto analizar los diferentes factores individuales y contextuales que afectan al desempeño y experimentar con diferentes configuraciones de equipo, comparando los diferentes posibles desempeños obtenidos de cada configuración. Particularmente, el trabajo desarrollado en esta tesis podrá ayudar a contestar preguntas tales como:

- ¿Qué pasaría si dos personas con un alto nivel de experiencia trabajan conjuntamente en el desarrollo de una tarea *simple* (de baja complejidad)?
- ¿Supondría un problema serio si dos personas con personalidades opuestas trabajan juntos en una misma tarea?
- ¿En qué medida afecta al desempeño global del equipo el que no exista una buena relación de confianza entre sus integrantes?
- Cuando uno o más integrantes del equipo de trabajo son afectados por emociones negativas (por ejemplo la ansiedad o el disgusto) respecto a las tareas que deben desarrollar, ¿cómo afecta esta situación al desempeño del equipo?
- ¿En qué medida es afectado el desempeño tanto individual como global cuando uno o más integrantes del equipo que prefieren trabajar individualmente son asignados a tareas en las que tienen que interactuar constantemente con sus compañeros?

El contribuir a responder a estas y otras preguntas ofreciendo información estadística relevante sobre el posible desempeño del equipo de trabajo a partir de la ejecución de varias simulaciones podrá ser de gran ayuda para los administradores de proyectos en la toma de decisiones sobre la correcta formación y configuración de equipos de trabajo.

Objetivos, contribuciones y limitaciones

A pesar de que en los últimos años los modelos de simulación son cada vez más utilizados para analizar y entender sistemas complejos, el modelar el comportamiento humano de manera eficiente sigue manteniendo varias líneas de investigación abiertas. Esto es debido principalmente al gran reto que representa el crear un modelo efectivo del comportamiento dada la *natural complejidad* del ser humano. El modelar adecuadamente el comportamiento diario al realizar actividades laborales no es una tarea fácil, dado que este comportamiento no está únicamente influenciado por las habilidades técnicas, la educación o capacitación de la persona, sino también por factores psicológicos y sociales. Nuevos métodos y técnicas han surgido en años recientes las cuales han contribuido de manera esencial a modelar tipos de comportamientos humanos en contextos y aplicaciones específicas, tales como aplicaciones militares [Traum et al., 2007], [Shen and Zhou, 2006]; entrenamiento y aprendizaje [Martínez-Miranda et al., 2008], [Core et al., 2006]; aplicaciones en entornos clínicos [Bickmore and Pfeifer, 2008], [Tartaro and Cassell, 2008], [Martínez-Miranda, 2010]; y para la representación de situaciones de crisis [Kozine, 2007], [Nygren, 2007], [Ozel, 1992] entre algunos otros.

El trabajo desarrollado en esta tesis propone el uso de Agentes de Software (entidades de software autónomas con la habilidad de interactuar con otros agentes y con su entorno) para modelar y simular el comportamiento humano dentro de un equipo de trabajo. En particular, el área de Simulación Social Basada en Agentes ha contribuido enormemente en el análisis de sociedades artificiales donde cada agente tiene una correspondencia uno a uno con los individuos que habitan el escenario real que se quiere analizar. La interacción entre los agentes basada en conjuntos de reglas corresponden a las interacciones que se dan entre los actores del escenario real [Gilbert, 2004]. Este tipo de modelos es posible gracias a la *simplificación* de las características de las entidades modeladas y la delimitación del contexto en el cual estas entidades *habitan*.

Siguiendo esta línea de investigación, la parte fundamental de esta tesis presenta y describe el modelo TEAKS (TEAm Knowledge-based Structuring) basado en agentes, en el cual un conjunto de atributos humanos modelan a un candidato real para integrar el equipo de trabajo. El comportamiento y desempeño de cada individuo será obtenido a partir de las reglas de interacción entre los miembros del equipo definidas por la influencia de los atributos individuales de cada agente sobre el desempeño y también por las características particulares del conjunto de tareas que simulan resolver.

La meta principal de este trabajo es el desarrollo de un modelo de simulación en el cual pueda representarse un equipo de trabajo para analizar las dinámicas asociadas a su desempeño en términos de:

- Tamaño adecuado del equipo (2 a n integrantes).
- Configuración adecuada al proyecto asignado (tipo de habilidades y atributos específicos de los integrantes del equipo).
- Correcta asignación de tareas (la tarea correcta para la persona adecuada).

El análisis de las dinámicas que afectan el desempeño ayudará a una mejor comprensión sobre los atributos (a nivel individual y colectivo) que afectan de manera significativa al desempeño de un equipo de trabajo. Para alcanzar el objetivo global propuesto, será necesaria la consecución de los siguientes objetivos particulares:

1. Estudiar e identificar el conjunto de factores humanos que influyen (positiva y negativamente) el desempeño de una persona frente a una tarea asignada.
2. Estudiar e identificar las características generales, pero importantes, de una tarea que influyen en el desempeño de la persona que la realiza.
3. Tomando como base las características previamente identificadas, se deberá desarrollar un modelo del comportamiento humano en equipos de trabajo. Este modelo deberá ser implementado como un software de simulación que permita la verificación y validación del mismo.
4. Realizar la validación del modelo a través del análisis de los resultados obtenidos para valorar la exactitud y fiabilidad obtenida y a partir de esto identificar mejoras y adecuaciones futuras.

Como en toda investigación, las hipótesis de trabajo y la delimitación del contexto deben ser claramente identificadas. En este sentido, las principales hipótesis definidas para este trabajo son cuatro:

1. Es posible modelar parte del comportamiento humano –específicamente el desempeño de una persona en un equipo de trabajo– como consecuencia de la interacción entre los atributos internos de una persona y las características generales de las tareas que realiza, así como también de la interacción con las

demás personas que trabajan en la misma tarea.

2. Dada la natural incertidumbre asociada con la caracterización de factores cognitivos, emocionales, sociales y de personalidad en una persona, la introducción de aleatoriedad sobre los valores en estos atributos (por ejemplo en el nivel emocional) ayudará a representar esta incertidumbre.

3. Al ejecutar un número significativo de simulaciones se podrá obtener información estadística relevante acerca del posible desempeño de los integrantes del equipo sobre cada una de las tareas asignadas y en consecuencia, se podrá obtener el posible desempeño global del equipo modelado.

4. A partir del análisis de los resultados estadísticos obtenidos de la herramienta de simulación, se podrán encontrar patrones de desempeño útiles que ayuden a la correcta selección y configuración de equipos de trabajo reales frente a un proyecto específico.

Por otra parte, las siguientes delimitaciones en el trabajo desarrollado deben tenerse en cuenta:

- El modelo propuesto (como todo modelo de estas características) es una representación abstracta del comportamiento humano real, en el cual los atributos elegidos son las piezas clave para inferir el posible desempeño de los individuos que forman un equipo de trabajo. Sin embargo es necesario tener presente que el conjunto de atributos elegidos ***no son los únicos*** que influyen en la complejidad del comportamiento humano.

- El trabajo propuesto en esta tesis ***no pretende*** modelar simultáneamente todas las escalas del comportamiento humano sino simplemente elegir un círculo de influencia que represente el comportamiento humano en el contexto de un equipo de trabajo a cargo de un proyecto dividido en tareas.

- El modelo desarrollado ***tampoco pretende predecir exactamente*** el comportamiento y desempeño de un equipo de trabajo, sino generar información estadística relevante que pueda ser utilizada como información adicional por los administradores de proyectos para la correcta selección e integración de un equipo de trabajo real.

Es importante señalar que la investigación llevada a cabo en esta tesis es un trabajo multidisciplinar y que abarca distintas áreas tales como Sistemas Multi-Agentes, Lógica Difusa, Administración de Recursos Humanos, Psicología, Sociología y Teoría Organizacional. Sin embargo, las principales contribuciones de esta tesis están principalmente enfocadas al área del modelado y simulación basada en agentes. En concreto, el trabajo desarrollado y los resultados obtenidos pueden ser de utilidad para las siguientes dos comunidades:

- ***A la comunidad de investigadores:*** este trabajo desarrolla un nuevo y original modelo basado en agentes que ayude en la toma de decisiones sobre la formación y configuración de equipos de trabajo. El modelo desarrollado representa y analiza el desempeño de los integrantes del equipo mediante cuatro categorías de atributos humanos: tipos de personalidad, emociones, habilidades sociales y capacidades cognitivas. Los fundamentos formales bajo estos atributos y las reglas de comportamiento son los Conjuntos y Lógica Difusa. El modelo propuesto es implementado en una herramienta de simulación que ha sido validada a través de la comparación de los resultados obtenidos por el modelo respecto a los resultados obtenidos en un equipo de trabajo real. El modelo y los resultados obtenidos descritos en este documento pueden ser de gran utilidad para ser comparados con otros modelos de características u objetivos similares de cara al desarrollo de futuros y mejores modelos para analizar y representar el comportamiento humano en general y dentro de equipos de trabajo en particular. La experiencia adquirida y las limitaciones encontradas durante el proceso de validación puede ser igualmente de especial interés para investigadores con intereses similares para analizar y replicar el presente modelo y que pueda servir para mejorar los resultados obtenidos.

- ***A la comunidad industrial y empresarial:*** el desarrollo del software de simulación que implementa el modelo teórico propuesto debe ser una herramienta útil para *analizar* y *experimentar* con diferentes configuraciones de equipos. Los datos generados por esta herramienta será información adicional que los administradores de proyectos en entornos empresariales e industriales pueden utilizar durante el proceso de selección e integración de candidatos a formar un equipo de trabajo. Tal y como se explica en el capítulo de la validación (Capítulo 6), una parte de este proceso se realizó mediante la técnica *face validity* [Sargent, 2007] en la cual participaron diferentes administradores de proyectos reales. Además de contribuir con su experiencia en el análisis y validación de los resultados obtenidos, estos expertos en el área de administración de proyectos contribuyeron con sugerencias y comentarios de cara a mejorar la usabilidad del software de simulación. La mayoría de estas sugerencias han sido incorporadas a la versión final del software para asegurar una mejor aceptación y simplificar la curva de aprendizaje de los usuarios. A pesar de que la versión final del software de simulación es un prototipo no comercial, el software y los resultados obtenidos fueron evaluados como bastante útiles y utilizables en escenarios específicos (ver sección 6.3 del Capítulo 6).

Contenido del documento

El trabajo desarrollado en esta tesis doctoral está dividido en tres partes fundamentales: en la primera parte se describen de manera general las diferentes técnicas y teorías en el modelado del comportamiento humano, poniendo especial énfasis en el área del modelado basado en agentes y simulación social. En esta parte se presentan también los fundamentos teóricos de las diferentes disciplinas que muestran la importancia e influencia de determinados factores tanto personales como sociales sobre el comportamiento humano en general y sobre el desempeño frente al desarrollo de actividades laborales en particular. La segunda parte del documento presenta la principal contribución de esta tesis a través de la descripción detallada del modelo TEAKS y su implementación en el prototipo final del software de simulación. En la tercera parte la validación del modelo, a través de la comparación de resultados obtenidos de un escenario real, es detallada. En esta parte se discute el proceso de validación, así como los resultados obtenidos y sus limitaciones. Estas tres partes principales son complementadas con una sección introductoria y otra de conclusiones y trabajo futuro.

En concreto, este documento de tesis está dividido en los siguientes 7 capítulos:

Capítulo 1. Este capítulo introductorio presenta el contexto en el cual se enmarca el trabajo de investigación desarrollado en esta tesis. Las primeras secciones de este capítulo presentan la importancia de llevar a cabo una correcta selección y formación de equipos de trabajo en contextos empresariales y organizacionales. Se profundiza especialmente en el riesgo que los administradores de proyecto deben asumir cuando la formación de estos equipos está únicamente basada en la información individualizada de los candidatos y no existe ninguna referencia a su posible desempeño como parte integral del equipo. Posteriormente se describe la propuesta de investigación desarrollada en esta tesis presentando la manera en cómo se plantea obtener información adicional precisamente sobre el posible comportamiento y desempeño de los candidatos a formar el equipo cuando éstos interactúan entre ellos y respecto a las tareas asignadas dentro del proyecto a su cargo. Las motivaciones tanto personales como profesionales que han originado este trabajo también son presentadas en este capítulo. En este capítulo se identifican también el objetivo general y los objetivos específicos que deberán alcanzarse para la finalización exitosa de este trabajo, así como las hipótesis de trabajo sobre las cuales se asienta el desarrollo de esta investigación. Finalmente, se delimita el contexto y alcance de esta investigación complementándose con las principales contribuciones aportadas tanto a la comunidad científica como a la comunidad industrial.

Capítulo 2. En este capítulo se presentan los fundamentos teóricos y que son los pilares esenciales que soportan esta investigación. El capítulo introduce la importancia y aplicaciones del modelado del comportamiento humano así como los diferentes prismas desde los cuales se ha enfocado este reto, poniendo un énfasis especial en el modelo basado en agentes. Algunos modelos con objetivos y características similares y las principales diferencias respecto al modelo desarrollado en esta tesis son presentados también en este capítulo. Posteriormente se profundiza en los aspectos teóricos actuales relacionados a los factores individuales y sociales que determinan e influyen en el comportamiento de una persona. Esta revisión se ha hecho desde una perspectiva multidisciplinar incluyendo avances de diferentes ramas dentro de la psicología, sociología, teoría organizacional y administración de recursos humanos. En concreto, diferentes teorías y estudios sobre cuatro aspectos y sus principales atributos en relación al comportamiento humano son descritos: capacidades cognitivas, estados emocionales, tipos de personalidad y habilidades sociales. Complementariamente, la descripción de algunos modelos actuales, implementaciones y aplicaciones de cada uno de estos factores en sistemas artificiales completan el contenido de este capítulo.

Capítulo 3. Tomando como base los fundamentos teóricos presentados en el Capítulo 2, el desarrollo del modelo TEAKS es detallado en este capítulo describiendo la arquitectura general del modelo y las características de cada uno de los componentes principales. La estructura interna de los agentes que representan a los candidatos reales a integrar el equipo, formada por un conjunto de atributos *cognitivos* (rol de especialización técnica dentro del equipo, nivel de experiencia y nivel de creatividad), *emocionales* (por un lado, el interés y deseo de realizar las tareas asignadas, y la ansiedad y disgusto ocasionados por las particularidades de la tarea a desarrollar, por otro), de *personalidad* (amable, expresivo, analítico y dominante) y sociales (introversión/extroversión, preferencia a trabajar individualmente/en equipo y nivel de confianza hacia los compañeros de tarea) son detallados en este capítulo. La estructura del segundo componente principal del modelo es también explicada en este capítulo: el proyecto que el equipo de trabajo debe realizar. El proyecto asignado al equipo es modelado a través de su división en tareas individuales asignadas a cada agente. Estas tareas tienen un conjunto de atributos los cuales son utilizados para modificar el estado interno de los agentes y en consecuencia definir el comportamiento y desempeño tanto a nivel individual como a nivel de equipo. Cada tarea en el proyecto está definida por parámetros tales como *número de participantes* en el desarrollo de la tarea, la *duración* estimada, la *secuencia* de ejecución (algunas deben ser ejecutadas en paralelo y otras de manera secuencial), niveles de *dificultad* y *especialización*, y nivel esperado de *calidad*. Este capítulo concluye explicando una de las características principales del modelo TEAKS: la representación mediante conjuntos y lógica difusa de los atributos internos de los agentes y de algunas de las características de las tareas. En concreto, se detallan cada uno de los conjuntos y valores difusos definidos para cada atributo así como las variables lingüísticas pertenecientes a los mismos.

Capítulo 4. Este capítulo es una continuación del anterior y complementa la descripción del modelo TEAKS. La primera parte de este capítulo se enfoca en la descripción del conjunto de variables elegidas para representar la evaluación del desempeño, de manera individual, de cada uno de los agentes frente a las tareas asignadas durante el desarrollo simulado del proyecto. Las cinco variables consideradas incluyen el *nivel de objetivos conseguido*; la *duración* obtenida sobre la tarea respecto a la duración estimada; el *nivel de calidad* obtenido en el desarrollo de la tarea; *el nivel de colaboración* que cada agente desarrolla respecto a los compañeros de tarea; y el *nivel de supervisión requerido* por cada agente durante el desarrollo de la tarea. De manera similar a los atributos individuales y del proyecto, este capítulo explica la representación de las variables de desempeño a través de conjuntos y valores difusos. La segunda parte de este capítulo se concentra en la descripción detallada sobre la manera de generar el comportamiento de cada agente en el equipo. En particular, se presenta el proceso de tres pasos y el algoritmo que lo implementa desde la asignación de tareas a los agentes hasta la obtención de los resultados del desempeño en cada tarea del proyecto. En cada paso del algoritmo se describe la evolución de los valores internos de cada agente influenciados por las características de las tareas a realizar y por las características de los compañeros de equipo. Las modificaciones y actualizaciones de cada atributo vienen dadas por el conjunto de reglas difusas de razonamiento que se ejecutan acorde a los valores internos de los agentes y los valores contextuales. En este capítulo también se describe el modelo sobre la evolución del nivel de confianza entre los agentes y cómo esta afecta al desempeño sobre las tareas. El capítulo 4 también presenta la manera en que se obtiene el desempeño global del equipo respecto al proyecto a través de dos variables: la *duración* y el *nivel de calidad* en la totalidad de las tareas del proyecto.

Capítulo 5. El modelo TEAKS desarrollado en esta tesis ha sido implementado como una herramienta de simulación a través de la cual, el administrador de proyecto puede configurar y experimentar con diferentes equipos virtuales. El capítulo 5 describe esta implementación comenzando con la justificación y descripción de las librerías de software utilizadas. Posteriormente se describen los distintos tipos de agentes desarrollados en la herramienta de software: los agentes que representan a los candidatos reales a formar el equipo, y los agentes que implementan funcionalidades específicas para la correcta ejecución del proceso de simulación. El proceso de comunicación entre cada uno de los agentes implementado en el sistema, es también detallado en este capítulo. La parte central de este capítulo presenta las funcionalidades de usuario del sistema, desde la manera de crear y configurar a los agentes que integrarán un equipo y las tareas que formarán el proyecto a realizar, hasta la visualización gráfica de los resultados generados por el sistema, pasando por el proceso de asignación de tareas. El capítulo termina describiendo el proceso de validación de la implementación utilizando datos empíricos para probar las principales funcionalidades del sistema y la correcta ejecución de las reglas difusas de razonamiento. Los resultados obtenidos de esta validación inicial son enumerados y discutidos al final del capítulo.

Capítulo 6. Este capítulo describe el proceso de validación realizado al modelo. En la introducción de este capítulo se presenta a la institución en la cual se llevó a cabo la validación: el Instituto Mexicano del Petróleo (IMP). El IMP es un centro de investigación y desarrollo tecnológico enfocado principalmente a desarrollar tecnologías relacionadas con la extracción y producción de crudo. Una de las principales ventajas de esta institución es la gran cantidad de proyectos que se llevan a cabo cada año y los cuales involucran a un número importante de expertos en diferentes áreas de conocimiento, cada uno de ellos con distinta formación y perfiles profesionales. Esta heterogeneidad ha sido el contexto ideal para validar el modelo debido a la importancia que tendría para los administradores de proyectos el tipo de información generada por el software de simulación. Dos técnicas de validación han sido utilizadas y presentadas en este capítulo: *historical data validation* y *face validity* [Sargent, 2007]. La primera hace referencia a la comparación de los resultados obtenidos por el modelo respecto a datos históricos de un equipo de trabajo real. La segunda técnica se refiere al análisis de los resultados generados por el modelo, hecho por expertos en el área de aplicación, es decir, por administradores de proyectos experimentados. La primera de las técnicas, *historical data validation*, fue utilizada para comparar los resultados en el desempeño a nivel individual de los miembros del equipo. La segunda técnica de validación, *face validity,* fue utilizada para evaluar los resultados a obtenidos a nivel global, es decir, validar los datos sobre el desempeño a nivel de equipo generados por el modelo. Para realizar la validación, los datos de un equipo y proyecto reales fueron consultados, y la información referente a los perfiles personales y profesionales de los miembros fue utilizada para crear a los agentes del equipo virtual en el software de simulación. Del mismo modo, la información de las características del proyecto fueron los datos de entrada para representar las tareas que fueron asignadas a los miembros del proyecto. El proyecto en cuestión era el desarrollo de un sistema de información geográfica para uso interno en el IMP y consistía de 23 tareas asignadas a un equipo de 23 personas. Los datos específicos y las adaptaciones necesarias al modelo son detallados en este capítulo. La parte central de este capítulo describe y analiza los resultados obtenidos, presentando estadística y gráficamente las diferencias entre los resultados del modelo y los resultados reales. Adicionalmente, este capítulo presenta un análisis detallado sobre el efecto que el nivel de confianza entre los agentes tiene sobre el desempeño frente a sus tareas. Algunas variaciones en los valores iniciales de confianza fueron introducidas para comparar los resultados de diferentes simulaciones. Este capítulo finaliza enumerando los problemas y limitaciones encontrados durante el proceso de validación, pero que no invalidan los prometedores resultados iniciales.

Capítulo 7. Este capítulo final presenta un breve resumen del trabajo realizado y de sus principales contribuciones al campo del modelado del comportamiento humano e implementación en sistemas artificiales. Adicionalmente, en este capítulo se enumeran y describen algunas posibles extensiones al modelo, tales como complementar los actuales roles *técnicos* de los agentes, con algunos roles *sociales* (por ejemplo el rol de líder), los cuales de acuerdo a la literatura son una importante influencia para el positivo o negativo desempeño de un equipo de trabajo. Otra extensión que se menciona en este capítulo es la referente a incluir un modelo de *factores externos* que afecta al desempeño tanto individual como de equipo. Estos factores externos representarían cambios importantes en el desarrollo *normal* de las tareas llevadas a cabo por los integrantes del equipo, tales como modificaciones en los requerimientos por parte del cliente, cambios en las políticas de la organización, entre algunas otras. Finalmente, algunas mejoras funcionales al software de simulación son también presentadas y discutidas en este capítulo final.

Conclusiones.

El trabajo presentado en esta tesis es el resultado de varios años de investigación multidisciplinaria en los que conceptos y teorías de diferentes áreas tales como Inteligencia Artificial, Sistemas Complejos, Psicología, Sociología, Teoría Organizacional y Administración de Recursos humanos fueron estudiados y analizados. Estos estudios permitieron el diseño, desarrollo, implementación y validación de un sistema basado en agentes en el cual, agentes de software fueron creados para representar individuos en el contexto de un equipo de trabajo desarrollando tareas específicas de un proyecto. La implementación de este modelo en una herramienta de software de simulación, proporciona una ayuda adicional (a los administradores de proyectos) en el proceso de toma de decisiones relacionado a la formación y configuración de equipos de trabajo.

Adicionalmente, el desarrollo del modelo TEAKS presentado en esta tesis provee una herramienta adecuada para el análisis de las diferentes dinámicas involucradas en el desempeño de un equipo de trabajo. La inclusión y representación de estas dinámicas dentro del modelo desarrollado ha permitido la obtención de información estadística relevante sobre el posible comportamiento y desempeño tanto a nivel individual como a nivel colectivo del equipo.

Es precisamente el desarrollo de este modelo construido a partir del estado del arte multidisciplinario actual de las dinámicas del comportamiento humano, una de las principales contribuciones teóricas de esta tesis. Particularmente, la revisión de teorías y estudios descrita en el capítulo 2 de este documento, presenta la importancia de algunos atributos individuales y sociales como principales influencias en el comportamiento y desempeño laboral en individuos y grupos. La representación de estos factores y sus relaciones a través de conjuntos y reglas difusas es otra de las contribuciones de esta tesis, aportando nuevas experiencias a la ya existente evidencia previa sobre la conveniencia del uso de lógica difusa en este tipo de modelos de sistemas complejos.

Pero el trabajo desarrollado en esta tesis no contribuye únicamente con aspectos teóricos, sino también proporciona resultados prácticos a través del desarrollo del software de simulación que implementa al modelo teórico. La herramienta de simulación TEAKS facilita a los usuarios principales (administradores de proyectos), el análisis sobre diferentes configuraciones de equipos a través de la experimentación alterando las características inherentes al escenario de estudio. Al tener la posibilidad de modificar las dinámicas individuales, sociales y contextuales incluidas en el modelo, se pueden obtener respuestas a preguntas específicas y entender mejor la influencia que tienen determinados atributos en el desempeño final de un equipo de trabajo. Esto ha sido corroborado a través de la validación del modelo utilizando información de un caso de estudio real llevado a cabo en el Instituto Mexicano del Petróleo, un centro de investigación y desarrollo de gran escala. Los resultados iniciales obtenidos durante este proceso han sido bastante prometedores, y aunque algunas limitaciones han sido encontradas, esto ha ayudado a identificar futuras líneas de investigación y desarrollo que contribuirán a mejorar el excitante y desafiante reto del modelado de comportamientos humanos en sistemas artificiales.

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Chapter 1

Aims of this Work

1.1. Introduction

When a new complex project begins in industry, usually the project manager(s) is responsible of partitioning this project into tasks and selecting the people who will perform them. The suitable selection of people to configure a successful work team is not a trivial decision-making process due to several complex factors that influence the individual and team performance. Nowadays most of the team formation process is typically performed by the project managers, who base on their past experience and available (though frequently scarce, uncertain and dynamic) information about personal and professional characteristics of the potential team members.

The success of a project is greatly due to the personal expertise and responsibility of each member, but also to an adequate communication, collaboration and co-operation between the individual team members [Biegler et al., 1997]. Often, a good work team performance also depends directly on the personal characteristics of each team's member, such as social skills and personality traits [Morgeson et al., 2005], making these human characteristics of vital importance in projects where the interaction and communication between the team members are fundamental for the achievement of the final objective. Additionally, the emotional state of a person plays a critical role in rational decision-making, perception, human interaction, and human intelligence [Picard, 1997], affecting its own performance and the performance of the whole team during the project [Fisher, 2000].

The research work described in this document presents the theoretical foundations, the implementation and validation of an innovative agent-based simulation model aimed to support the formation and configuration of work teams. The proposed model uses the advances in the state of the art in the fields of **Artificial Intelligence** and **Complex Systems** to simulate the collective behaviour of a virtual (but realistic) work team. This introductory chapter describes the context in which this research work has been developed as well as the personal and professional motivations in the selection of the specific research topic. Furthermore, this chapter introduces with more detail, the scope of the problem and the set of proposed hypotheses. The main goals and the specific objectives of this research are also presented in this chapter. The last part of this chapter describes the main contributions and benefits that this work offers to both, the research and the industrial communities.

1.2. Scope of the Problem

In an ideal world, every project manager(s) in charge of work teams' integration should have information about the personal and professional profile of the possible candidates to integrate the team. Fortunately, there are several available tests in the Human Resources Managers area to measure some human characteristics, ranging from the classical IQ tests for cognitive abilities, to those tests used to measure some psychological characteristics such as Emotional Intelligence, Relationships, Personality, Communication Skills and so on (see for example, http://www.queendom.com/tests/index.html). The information obtained from these tests may be used to know in more detail the characteristics of the candidates and can be used as helpful information to select the right person for the right job. Nevertheless, in most of cases this information is not enough to predict the possible collective behaviour that leads to the success or failure of the work team formed by these persons when they are jointly interacting facing a specific project.

It could be even more useful for project managers to use the results of the cognitive and psychological tests to build *virtual work teams* and simulate its possible behaviour to analyse what could happen when people with specific characteristics interact between them and with their respective tasks through the entire duration of the project. The use of computer simulations to analyse and understand complex phenomena have been well applied in several and different research domains. Computer simulations allow playing with the behaviour of the modelled phenomenon under study by changing the conditions of its environment and its internal parameters, and observing the consequences in a controlled environment. This method is useful in many situations where such task in real life would imply a high cost or would be impossible to realise.

The development of a model to simulate the behaviour of a specific type of work team would help project managers in the decision-making process about the selection and assignment of the tasks for the team members. Playing with different possible work team configurations, project managers could get the answer to questions such as:

- What would happen if two people with high experience are working together in a *simple* (not complex) task?
- Would it be a serious problem if people with opposite personalities work on a shared task?
- How does the lack of a good trust relationship among the team members affect to the global work team performance?
- What is the impact on the global work team performance of one or more team members leaving the team temporarily or permanently?
- In the case that one or more team members feel disgust, anxiety or other negative emotion towards some specific tasks, how this will affect the global performance of the work team?
- How is team performance affected if two or more team members, who prefer to work alone, are put to work jointly in several tasks?

Answering these and other questions based on statistical data related to the possible work team performance would definitely benefit the decision-making process of the work teams formation and configuration.

1.3. Research Approach

Since one of the goals of Artificial Intelligence (AI) is to design and implement systems that simulate human behaviour [Minsky, 1995], this work proposes that some AI techniques can be very useful to model and simulate human behaviour within a work team. From this model, a software simulation tool can be built to get the statistical information about the possible work team performance and help project managers in the most suitable configuration of real work teams.

The modelling of human behaviour is a great challenge due to the instability, unpredictability and the ability to perform independent actions of human nature. This behaviour when performing daily activities at work is influenced not only by ability, training and education, but also by psychological states and traits [Furnham et al., 1999]. That is the reason why humans cannot be modelled in the same way as machines are modelled into a production line. However, in recent years several models and techniques have emerged that clearly indicate that some contextual-limited modelling of human-like behaviours are possible such as in military applications [Traum et al., 2007], [Shen and Zhou, 2006]; training and learning [Martínez-Miranda et al., 2008], [Core et al., 2006]; applications in health [Bickmore and Pfeifer, 2008], [Tartaro and Cassell, 2008], [Martínez-Miranda, 2010], and for the representation of crisis and emergency situations [Kozine, 2007], [Nygren, 2007], [Ozel, 1992] among others.

This work proposes the use of Software Agents (which are autonomous software entities with the ability to interact with other agents and with the environment) to model and simulate the human behaviour within a work team. Moreover the Agent-Based Social Simulation research area has helped to analyse artificial societies where each agent has a one-to-one correspondence with the individuals that exist in the real world and the interactions between the agents can likewise correspond to the interactions between the real world actors [Gilbert, 2004]. This kind of models is possible due to the *simplification* of the human characteristics and the limitation of the context where the desirable human performance model make sense. These human simplification and context limitation are valid given that "*one model usually is the simplification –*

smaller, less detailed, less complex, or all of these together- of some other structure or system" [Gilbert and Troitzsch, 2005].

Following this line, the research work presented here describes the TEAKS (TEAm Knowledge-based Structuring) agent-based model where a set of human characteristics is selected to model the individual's behaviour within a work team. Each software agent represents a real person through the selected set of human characteristics and its behaviour is a consequence of the interaction with its team-mates and their assigned project's tasks. The outcome result of the agent's behaviour is measured through other set of selected parameters that will form the agent's performance over the assigned tasks.

From the TEAKS model, a software simulation tool is developed and used to *play* with several work team configurations. A given number of simulations are executed based on different work team configurations, to get statistical information about the possible team performance with different configurations. The obtained information then can be used by project managers to take decisions in the final selection of the candidates to form the real work team.

1.4. Motivation and Goals

My first contact with the research world was in summer of 1999 at the Computation Research Centre in Mexico City. I began to work at the Agents Laboratory collaborating in the design and development of the EVA project (*Espacios Virtuales de Aprendizaje*, Virtual Spaces for Learning) analysing the improvement of the system through the use of software agents. When I decided to start a Ph.D., I was convinced about my preference in the development of a research work on the Artificial Intelligence area, and specifically I was very interested in the application of Multi-Agent systems and software agents to real world problems.

Also, when I was working as Head of the software development department in a private company (before starting my research activities), I found that one of the most common problems when a new software project starts is the selection (including the hiring) of the people to work on the project. As stated before, many times the project leader needs to form the work team with the available people in the company, but many times these people have not worked jointly before as a work team. By that time, the first thoughts on a software tool that could offer suitable information about the possible performance of a set of people working together came to my mind. ***Explore this idea and provide the basis for the development of this simulation tool*** is the main motivation of this research work.

1.4.1. Goals

The main goal of this research is the design and development of a model to represent a work team and analyse its associated dynamics in terms of:

- the size of a team (2 to n members),
- composition (specific skills of the people involved in the project) and
- the tasks assignment (the right task for the right person).

The analysis of these work team dynamics would allow a better understanding of the attributes (at individual and global levels) that significantly affect the performance of a work team.

To fulfil this global goal the following specific objectives need to be achieved:

1. Study and identify the set of human factors that influence (both in a positive and negative way) the performance while facing the development of a project's task.
2. Study and identify relevant and general characteristics of a task that influence the performance of the person that is working on it.
3. Develop a model of human behaviour within work teams taken the above identified characteristics as the main basis. This model needs to be implemented in a software simulation tool allowing the verification and validation of the proposed model.
4. Validate the model through the analysis of the results to assess the correctness of the model and identify further improvements.

As in every research work, the main hypotheses and limitations need to be correctly identified to assess the obtained results. These hypotheses are presented as following.

1.5. Hypotheses and Limitations

The main hypotheses of work used in this research are four:

1. It is possible to model an abstract representation of human behaviour and more specifically human behaviour within a work team as a consequence of the interactions among the internal attributes of a person (cognitive characteristics, emotional state, social characteristics and personality traits) and some characteristics of the specific task(s) assigned to the person. An additional influence factor on the person's behaviour is also the interaction with the rest of the team members' internal attributes.
2. Given the uncertainty associated with the characterisation of the cognition, emotion, personality and social properties of a person, random probabilities around the fixed values of some attributes (such as the emotions) can help to model this uncertainty.
3. The execution of several simulations of the interaction described above would provide useful information about the possible performance of the modelled team members. Then, the possible performance of the whole work team can be inferred from this information.
4. The results obtained about the possible team performance can be statistically analysed to find useful patterns that support the decision making process in the selection of the people to configure a real work team facing a specific project.

In addition, the following limitations of this research must be considered:

- The proposed model (as every model) is an abstract representation of real people, where a basic set of human characteristics are selected as the key factors to reproduce the possible behaviour in a work team. Nevertheless, it is necessary to have in mind that the selected attributes ***are not the unique*** ones that affect and form the complexity of human behaviour.

- This research ***does not*** pretend to model all scales of human behaviour simultaneously, but choosing one circle of influence for representing human behaviour within the context of a work team in charge of a project.

- This research either ***does not*** pretend **to predict** the performance of a work team, but to generate useful statistical information about it that can be an additional help for project managers. Although one of the main objectives in this research is to provide a simulation tool to support project managers in the formation of work teams, at the end of the day, the project manager is the responsible to decide the real configuration of the team.

1.6. Contributions

The research described in this document is a multi-disciplinary work and combines concepts and methods from different areas such as Multi-Agent Systems, Fuzzy Logic, Human Resource Management and Psychology. Nevertheless, the main contributions achieved during the development of this work were mainly focused in the field of Agent-Based Modelling and Simulation. In concrete, the developed work and its results can be useful for two communities:

- ***To the research community***: this research proposes an original agent-based model that supports the decision-making process in the formation and configuration of work teams. This model represents and analyses the performance of team members using four categories of human attributes: personality trends, emotions, social skills and cognitive capabilities. The formal roots underlying the agents' attributes and behaviour are Fuzzy Sets and Fuzzy Logic. The model is implemented in a simulation tool that has been validated by comparing the simulation results in the work team performance against results obtained from a real work team. The model and the results reported are valuable to be compared with other similar models and contribute in the development of better and more complete models for the analysis and representation of human behaviour. The experiences and limitations found during the validation process can be also valuable for researchers with similar interests by analysing and replicating the presented model to improve the current results and extend the approach to face different human attributes and different types of projects.

- ***To the industrial community***: the development of a software simulation to analyse and *play* with different work team configurations would support Managers of industrial projects with an additional and useful tool in the process of team candidates selection. As it is explained in Chapter 6, part of the model validation was developed using the *face validity* technique [Sargent, 2007] where different project managers were involved. Additionally to their contribution in the validation of the results, the project managers contributed with several comments and suggestions regarding the usability of the software. Much of this feedback was incorporated to the final version to assure a better adoption and facilitating the learning curve to the main target users. Although the final version is still a prototype, the software and its results were found useful and usable for specific scenarios (see section 6.3 of Chapter 6).

1.7. Roadmap

The research work presented in this document consists basically of three main parts. In the first part, the related work and the theoretical background of the model is presented. Also the description of the TEAKS model is introduced through the description of each one of its components. The second part describes the implementation of the model into the software simulation tool and the empirical validation of the results. Finally, the third part of the document explains the validation of the model through the description of the case of study and the identification of further research lines. These three conceptual sections are structured into the following 7 chapters:

Chapter 1. This introductory Chapter presents the generalities of the work. Chapter 1 also introduces the underlying motivations to develop this research as well as the general goal and the specifics objectives. The hypotheses and limitations of this research are also enumerated and the main contributions described.

Chapter 2. This chapter presents an overview of the relevant work used as the theoretical roots of the model proposed in this thesis. The chapter starts by a rationale on the usefulness of models of human behaviour by explaining the goals, advantages and applications of this kind of models. Then a brief review of the most used techniques in the modelling of human behaviour is presented, with focus on agent-based modelling. This chapter also presents some of the research work that justifies the importance of *cognition, emotions*, *personality traits* and *social-related* factors as attributes that directs the human behaviour and human performance at work. Additionally, an overview of current computational models that include one or more of these human attributes developed for different approaches and specific purposes is also presented.

Chapter 3. This chapter introduces the general architecture of the TEAKS model. The chapter is basically concentrated in the description of the internal model developed in the TEAKS agents for the representation of the real team candidates. Additionally, this chapter also describes how a project is modelled in TEAKS by its division into a set of identified and limited number of tasks. The last part of this chapter explains the use of fuzzy logic in the TEAKS model through the *fuzzification* of some of the attributes used in the model to achieve a *better* and *more realistic* representation of the defined human and task attributes.

Chapter 4. This chapter describes the model that TEAKS implements to evaluate the individual and work team performance. In concrete, the model consists of a set of five performance metrics to evaluate the individual and the work team performance. The representation of each one of the performance indicators through the use of fuzzy sets is also explained in this chapter.

Moreover, the model of interaction and behaviour between the team members has been also addressed in this chapter 4. The general algorithm defined to generate the behaviour and performance of each agent through the simulated execution of the project is presented and the specific steps in the algorithm are also detailed.

Chapter 5. This chapter describes the implementation of the TEAKS model into a software simulation tool. The design requirements and the software components used to develop the simulation tool are explained. The chapter also presents the multi-agent architecture where the *system agents* and *team member agents* as well as the communication protocols between them are described. The main functionalities of the TEAKS simulation prototype and the implementation validation process are also explained in the last part of the chapter.

Chapter 6. In this chapter, the validation of the TEAKS model is described through the use of the *face validity* and the *historical data* validation approaches in a real case of study developed at the Mexican Petroleum Institute (IMP). The first part of the chapter describes how the data from the real scenario were identified to be used as the input to the TEAKS simulation software. The chapter also describes how the historical data validation was done through the evaluation of the TEAKS results by comparing the obtained performance at the individual level from the TEAKS simulation software among the evaluation records of the participants in the real work team. Additionally, the chapter describes the face validity approach through the analysis of the obtained results by some project managers of the IMP. Finally, the chapter presents the analysis made over the *trust* relationship between the TEAKS agents to observe how the values in this attribute evolve throughout the simulated execution of the project and see the effect of it in the final work team performance.

Chapter 7. This final Chapter presents a summary of the main contributions carried out in this thesis. This Chapter also describes some interesting and promising directions for further work that could improve the TEAKS model and the current obtained results.

1.8. Summary

This chapter introduces the generalities of the work developed in this thesis by explaining the context, the general goal and main objectives as well as the underlying motivation of this research. This chapter also enumerates and describes the formulated hypotheses of work and confines the scope of the research by presenting its limitations and the main contributions of the work. Finally, the structure of the thesis is presented.

Chapter 2

Modelling the Human Behaviour: Is it Possible?

Human behaviour flows from three main sources: desire, emotion and knowledge
Plato, 427 – 347, BC.

2.1. Why to Model the Human Behaviour?

The study and understanding of human behaviour has been one of the topics under discussion during many years, even addressed by the philosophers from the ancient Greece (see for example [Long, 1986]). More recently, with the great development of the computing sciences, the modelling and simulation of different aspects that form the human behaviour has been an interesting and increasing area of research. According to [Fan and Yen, 2004], the modelling and simulation of human behaviour is important mainly for four reasons:

(1) It *offers sufficient practice for human training*.

(2) It *is a practical solution to improving readiness and lowering costs*;

(3) It *can be used for conducting "what-if" scenarios,* and

(4) *Simulations of what actually occurred can be used for after-the-fact analysis*.

All four reasons are related with the fact that simulating different facets of human behaviour provides virtual but realistic scenarios where the internal (at the individual) and external (contextual) dynamics that affect and produce human behaviours are modelled and can be altered to *play*, analyse and learn about the effects of these changes in the overall simulated scenario. The development and use of these models representing human behaviour is useful to support on one side the establishment of hypothesis and forecasts about the evolution and consequences of the modelled behaviours *before* the real situation occurs, and, on the other hand, support a deep understanding of what happened by representing the relevant characteristics of the real scenario once *it has occurred*.

Although the modelling of human behaviour is a great challenge due to the instability, unpredictability and the ability to perform independent actions of *human nature*, several models and techniques have emerged in recent years that clearly indicate that some contextual-limited modelling of human-like behaviours are possible such as in military applications [Traum et al., 2007]; [Shen and Zhou, 2006]; [McNally, 2005], training and learning [Martínez-Miranda et al., 2008]; [Zakharov et al., 2007]; [Core et al., 2006]; [McLaughlin et al., 2002]; testing and evaluation (e.g. of user interfaces [Bonnie and Dario, 2005]); operation analysis [Baines et al., 2005]; the analysis of consumer behaviours [Siebers et al., 2010], [Patel and Schlijper, 2004] and the representation of crisis and emergency situations [Kozine, 2007], [Nygren, 2007], among others.

2.2. How to Model the Human Behaviour?

2.2.1. Human Behaviour as a Complex System

The complexity is increased when models of human behaviour include the representation of people interacting with others. Realistic models of human behaviour should include this important scenario because humans, as social beings, are highly influenced by the interaction with other humans during the every-day activities. This non-linear interaction is fundamental in the context of groups or teams where individuals are sharing information, resources and working towards a common objective. Given these characteristics, the simulation of human behaviour as part of a group can be considered as a *Complex System:* "*Complex systems consist of a number of components, or agents, that interact with each other according to sets of rules that require them to examine and respond to each other's behaviour in order to improve their behaviour and thus the behaviour of the system they comprise*" [Stacey, 1996].

Over the past few decades, tools and techniques for modelling and predicting human behaviours in complex systems have evolved and matured. [Elkind et al. 1990] propose the following classification of human behaviour models:

- **Bio mechanical models.** Where aspects of the physical movement of the body, using laws of physics and engineering concepts to describe the motion undergone by various body segments and the forces acting on them. They are used in practice to predict human material handling capabilities or to study human tolerance limits for vibration and acceleration stress [Kroemer et al., 1988].

- **Knowledge based/cognitive approach.** These models of human performance are explanations of how people decide what is to be done to solve a problem. This approach treats human thought as an example of symbol manipulation according to rules that can be modelled with computer programs, but without assuming that the human brain works like a computer [Bass et al., 1995], [Sasou et al., 1996].

- **Optimal control theory models.** The human being is viewed as an information processing or control/decision element within a closed loop system. In this context, information processing refers to the processes involved in selectively attending to various sensory inputs and using this information to arrive at an estimate of the current state of the world [McCoy and Levary, 2000], [Baron, 1984].

- **Task network models.** The human is assumed to interact with the environment through a sequence of activities or tasks which are described by an operator action, an object of that action, and other qualifying descriptive information. The human is assumed to be sensitive to global variables such as stress or motivation, and the approach also includes estimates of human and system reliability [Sebok and Hallbert, 1997], [Wetteland et al., 2000].

- **Anthropometric models.** These models deal with the ability of an operator of a given physical size to work within a given space, to reach specific controls and to see specific displays. They were developed specifically to enable ergonomic design activities to be undertaken in a CAD environment, and their principal feature is a 3D animated mannequin [Baddler et al., 1993].

- **Workload prediction models.** They can be defined in terms of physical or mental properties. The human is assumed to have a number of available channels. The issue here is whether one can predict the change in performance, given the characteristics of either, the processing on each channel in isolation or the relationships between channels. Some researchers have recently begun to question the whole concept of multiple resource allocation theory, which is central to many of the current approaches [Archer and Locket, 1997].

- **Situational awareness models.** This kind of models can be described as knowing what is going on, so that one can figure out what to do. The aim is to assess the operator's knowledge about spatial orientation, positional awareness, temporal awareness, automation awareness and tactical situation awareness. These models have been used, for example, in military command and control systems and air traffic management [Corker 1999], [Sawaragi and Murasawa, 2001].

- **Human reliability models.** They refer to the effectiveness with which human and machines co-operate to accomplish tasks. Neither human nor machine is assumed to be the sole contributor to reliability. There are three general groups of approaches to the issue of reliability: human error occurs at the level of individual subtasks; human error is dependent upon processing mode; and human error is the product of a mismatch between problem-solving demands and resources [Yoshimura et al., 1988], [Shorrock and Kirwan, 1999].

- **Micro models.** They are often based upon a large body of empirical data, and have been developed for many different performance variables.

Integrated models incorporate a large number of such micro models in order to be able to treat human performance holistically [Mason et al., 2002].

- **Integrated models.** They typically attempt to address the human, the physical system, and the environment. They incorporate a large number of micro models in an attempt to model overall system effectiveness. Their validity may rely heavily on the way in which the components interact [Yow and Engh, 1997], [Bunting and Belyavin, 1999].

More recently, a relative new perspective to model and represent human behaviour within groups is ***Social Simulation***. Researchers in this field argue that the only general effective way of exploring non-linear behaviour is to simulate it by building a model and then running a simulation [Gilbert and Troitzsch, 2005]. This technique has been largely used in several research domains including Political Sciences [Yamakage et al., 2007], [Kottonau and Pahl-Wostl, 2003]; Economics and Social Sciences [Phan and Varenne, 2010], [Marks, 2007]; Environmental Sciences [Gernaey et al., 2004], [Belfore, 2003]; Natural Resource Management [López-Paredes et al., 2005], [López-Paredes and Hernández-Iglesias, 2008], [Galán et al., 2009]; Anthropology and Archaeology [Kohler and van der Leeuw, 2007]. In particular, human models developed in Social Sciences are applied for several purposes: e.g. the exploration and analysis of artificial societies [Gilbert et al., 2006] and the study of social norms within complex organisations [Neumann, 2010] among others.

A great number of social simulation models use *virtual entities* to represent real human beings through a selected set of human characteristics (relevant for the context of application). The development of these models has been increased in the last years mainly due to the great success of the *Distributed Artificial Intelligence* discipline, where the core concept is the notion of *agent*.

2.2.2. Agent Based Modelling

One of the main research areas that have contributed to the development of social simulation models is the field of agent based modelling (ABM) which has its roots on the Distributed Artificial Intelligence (DAI) [O'Hare and Jennings, 1996]. The key component in ABM is the concept of *Agent,* which is an autonomous software entity with the ability to interact (sociability) with other agents (including humans) and with the environment. Autonomy means that agents are active entities that can take their own decisions based on their own goals. This is not the same with objects, as they are predetermined to perform the operations that someone else requests them. An agent, however, will decide whether to perform or not a requested operation, taking into account its goals and priorities, as well as the context it knows. In this sense, the agent paradigm assimilates quite well the individual in a social system and some agent-oriented methodologies, such as the INGENIAS [Pavón et al., 2005], have been already applied to social simulation [Pavón et al., 2008a], [Pavón et al., 2008b].

In concrete, when considering the modelling of human behaviour within groups or teams, agent based models allow to integrate multi-disciplinary approaches for the different dimensions of the *teamwork behaviours,* including communication, coordination, coaching, collaborative problem solving and cross monitoring among others (a deep revision and analysis of works modelling teamwork behaviours is presented in [Fan and Yen, 2004]). These models get inputs from disciplines such as Business Management, Cognitive Science, Human Discourse and Distributed Artificial Intelligence to build multi-agent systems (MAS) that implement theories and concepts such as *joint intentions, team structure* and *shared plans/goals*. Examples of this kind of systems include COGNET [Zachary et al., 1992], GRATE* [Jennings, 1995], STEAM [Tambe, 1997], OAA [Martin et al., 1999], CAST [Yen et al., 2001], and Team-Soar [Kang, 2001].

A complementary approach is to apply agent based models to *simulate human behaviour* within groups and teams. Instead of *supporting the mechanisms* behind the teamwork behaviours such as in the works mentioned above, this approach allows to analyse the effects of specific human, social and contextual characteristics over the global behaviour and performance of the group/team. Examples of these works include models to analyse and understand the behaviour of a group of agents facing the management of common pool resources [Pahl-Wost and Ebenhöf, 2004], where the agents are characterised by a set of attributes such as the level of *cooperativeness, fairness (concerning others and concerning me), conformity, positive/negative reciprocity, risk aversion, commitment and trustworthiness* and the agent's behaviour is described by a set of decision heuristics based on the value of the agent's internal attributes and on the perceived behaviour of the other agents.

Similarly, [Luscombe and Mitchard, 2003] developed an agent-based model to analyse the performance of military combatants and studying the effect on their behaviour of individual and social factors (modelled within each agent) such as *cohesion* (the bond between the team members), *morale* and *fatigue* under three different battle scenarios: an *ambushing* scenario, *attack on a dug-in* scenario and *symmetric battle with two equal forces* scenario. Also [Wu and Hu, 2007] present an agent-based model where the group behaviour facing the adoption of a new e-government application is analysed. The model includes the representation of the groups of agents through attributes such as the *level of accepting information technology*, *existent power of groups*, *degree of obtaining interest* and the *value type* of the agents (used to define the type of incentive –economic, political or social– that can be disclosed to each agent to improve its current *degree of interest*). The simulated actions over the group of agents include the introduction of administrative measures and incentives to reduce the resistance and to improve the interest towards the introduction of the new technology respectively.

One type of teams particularly interesting (and in line with the work described in this thesis) is the one formed by people in front of their daily activities at work to perform a set of tasks. The analysis of the behaviour and performance of these work teams can support the decision making process of managers to select the right persons to form better work teams taking into account the fact that a group of people with optimal individual abilities may perform sub-optimally acting as a work team [Steiner, 1972]. From a research point of view, this scenario offers several dimensions to be studied given that, as stated in the Introduction chapter, the work team's performance is influenced not only by the personal expertise and responsibilities of each team member, but also by some personal characteristics such as social skills and personality traits plus an adequate communication, collaboration and cooperation between them [Morgeson et al., 2005].

Examples of works addressing the representation of different work teams' dynamics behind team behaviour and performance include the work by [Marreiros et al., 2005] for the selection of the appropriate agents to participate in group decision making. Each agent has three parameters used by a Register Agent to select the members to form a group: *the area of expertise, the interest topics* and *the availability* of the agent. When a group formation is required, the Register Agent sends an explicit *request* message to all the possible participants with information about the *expertise areas* needed. Each agent can respond according to its interests and availability to participate in the group. This model has been extended in [Marreiros et al., 2006] by including an emotional component with a large set of emotions: *joy, hope, relief, pride, gratitude, like, distress, fear, disappointment, remorse, anger* and *dislike*. Although there is a prototype of this model, where the user has to configure the rules behind the emotion selection mechanism, no specific analysis about the behaviour or performance in the formed group(s) is explained.

The work of [Dong et al., 2008] presents another agent-based model that intends to evaluate the effectiveness of a work team based on the relationships between the team members and the cost of processing the allocated tasks to each member. The model uses agents to represent the manager and worker members of the team using the following attributes: *technical* and *social skills* for completing a task; the *learning ability* while processing a task and a record of *received reward* in the worker after its performed task is evaluated by the manager. The model also uses agents to represent the tasks that the work team need to process with attributes such as the *technical* and *social competences* required to process the task, the *difficulty influence* and the *planning time* to perform it. The attributes are used then to define a set of rules to represent the *degree of relationship* between the team members, the strategy of the manager to allocate a task to each worker, and the *reward* or *punish* received after the evaluation of its assigned task. The team performance is obtained through the *average of task cost* (comparing the cost of processing the task against the task's planning task), the *relationship degree* among the team members and a combination of both. The model has been validated by comparing the results generated by the model with the results of a real work team of 15 members finding some similarities between them.

More recently, [Rojas and Giachetti, 2009] have developed an agent-based model to simulate the process of coordination activities within a work team. The objective of the so called Team Coordination Model (TCM) was the analysis and experimentation with different team configurations to determine the combination of team composition, organizational characteristics and coordination methods that have better performance for a specific job. Two main entities are modelled in this work: the team members and the job they simulate to perform. The agents representing the team members are modelled with attributes including *skills levels, training level* and *experience* plus *communication*, *task processing* and *decision-making* capabilities. The agents' job to be performed is represented as an activity network where each node represents a task with different types of interdependences between them and each task is characterised by *duration, complexity* and *priority* attributes. Different team configurations were tested to analyse the effect of changing some team parameters over the global performance measured with the *completion time* that the agents required to finish the job. The team parameters tested included the *team size*, the *team member experience*, the *team member teamwork skills* and *team centralisation* (the required degree that the team leader takes coordinating decisions instead of a distributed negotiation between the team members), among others. The model was validated in two ways: comparing the simulation results with collected data from a real team (plus a simulation results evaluation by a member of the real team) and using knowledge about team dynamic derived from existent literature. Both types of validation showed good initial results and the simulation provided some recommendations that could improve the performance of the real team in the selected validation scenario.

In the three above described examples, different *human attributes* are implemented inside the agents to represent real team members. These attributes include cognitive capabilities (e.g. the level of experience, the training level, technical skills, the learning ability, decision-making and area of expertise), social-related factors (e.g. social skills and communication capabilities) and even the emotional state. In an artificial model, it is hardly difficult to include all the internal human attributes that affect and direct the behaviour of a person. The most common strategy to follow is to select only those attributes that are important in the context of the phenomenon that will be modelled. So, in the context of human behaviour within work teams facing the development of specific tasks, the key attributes to be modelled in the agents to produce realistic and useful information about the possible individual and work team behaviour need to be identified.

2.3. What to Model in the Human Behaviour?

Even when the context where the phenomenon under study takes place is quite clear, the selection of the internal and external factors that affect human behaviour is not a trivial task. Although a model is an abstract representation of the real scenario, the basic components that form that scenario need to be included. In this sense, the following subsections present a brief review of existent research that indicates the importance of some specific internal and social attributes in human behaviour in the context of human behaviour at work and within work teams. Additionally, we review some existent artificial systems and architectures that implement these attributes.

2.3.1. Cognition

The research discipline that traditionally has focused on the study of human behaviour is the Psychology. Until the 1950s the psychological approach that dominated the study of human behaviour was the *behaviourism*. The behaviourism is based on the concept of understanding human behaviour through observation and believing that the environment is the cause of the different behaviours in humans. According to behaviourists, the study of human behaviour should restrict to examining the relation between observable stimuli and observable behavioural response banishing any mention to consciousness and mental representations.

Nevertheless, from the mid 1950s this perspective began to change dramatically towards the *cognitive approach* (an important influence that contributed to this change was the work of John McCarthy, Marvin Minsky, Allen Newell and Herbert Simon, the founders of Artificial Intelligence). The psychological cognitive approach focuses on how humans think with the belief that such thought processes affect the way in which humans behave. The interest and development of this psychological approach has been increased from the 1960s originating the Cognitive Science.

According to [Thagard, 2005], the central hypothesis of Cognitive Science is that *thinking can best be understood in terms of representational structures in the mind and computational procedures that operate on those structures,* i.e. the Computational-Representational Understanding of Mind. Although not all cognitive scientists agree with this hypothesis, it is currently the dominant approach to cognitive science and its success has been mainly due to the fact that it employs an analogy derived from the development of Computer Science. The mental processes studied in cognitive science include *comprehension, inference, decision-making, planning* and *learning*. All these mental processes produce, at the end, an *intelligent* human behaviour with the capabilities to develop highly routine tasks to extremely difficult, open-ended problems.

In the context of human behaviour at work, several studies along the years have proved the high influence of the cognitive abilities on work performance across different types of jobs [Hunter and Hunter, 1984], [Ree et al., 1994], [Tracey et al., 2007], [Marcus et al., 2007], [Zyphur et al., 2008]. One particular outcome originated from the different mental processes that has been deeply studied in the analysis of work performance is the *creative* behaviour [Gilson, 2008], [Shalley, et al., 2004]. Research has linked five specific cognitive abilities that influence creativity: problem framing, divergent thinking, mental transformations, practice with alternative solutions, and evaluative ability [Basadur, 1994], [Dansky, 1999], [Runco and Sakamoto, 1999], [Sternberg and O'Hara, 1999]. The concept of creativity has received much attention (mainly in the Organisational Psychology and Human Resources disciplines) as it is considered the *basic* ingredient to be innovative [Shalley and Zou, 2008], which in turn is a key factor to increase the success in the work performance of an individual, group or organisation [Feneuille, 1997].

Moreover, the cognitive and creativity research topics have not remained to exclusively understand work behaviour and performance at individual level, but both have been extended to cover the understanding and improvement of behaviour in work teams. In concrete, the term *team cognition* has been linked to effective team performance [Stout et al., 1996] and it includes knowledge about team members, task-specific information, and team processes [Fiore and Salas, 2004]. These factors are often represented as a *shared mental model* due to the hypothesis that mental models can be shared across individuals as in a group or team [Mathieu et al., 2000]. Shared mental models are most often described in terms of their elements and their interrelationships, focusing on differences [Banks and Millward, 2000] or on commonalities [Blickensderfer et al., 1997], [Stoyanova and Kommers, 2002].

Team cognition has also attracted the attention of researchers on creativity to analyse and better understand the creative processes and outcomes that take place at group/team level [Paulus and Nijstad, 2003]. But team cognition is not the only factor that influences a creative behaviour in work teams, different research are concentrated in other factors such as group diversity, minority dissent, group-decision making, brainstorming, and group support systems [Paulus, 2008], [Milliken et al., 2003], [Nemeth and Nemeth-Brown, 2003], [Stasser and Birchmeier, 2003], [Paulus and Brown, 2003], [Nijstad et al., 2003]. Additionally, other research works have proved the importance of contextual and environmental factors of the teams that also affect the creative behaviours such as group autonomy, group socialisation, mentoring, knowledge transfer and creativity at the level of cultures and societies [Levine et al., 2003], [Hooker et al., 2003], [Argote and Kane, 2003], [Simonton, 2003].

The development of systems that emulate or reproduce the aforementioned mental processes to exhibit an intelligent behaviour is the main aim of the Artificial Intelligence. Due to the computational-representational understanding of mind used in cognitive science, it is not surprising that there exist several artificial cognitive architectures which model different mental processes. Examples of these architectures include SOAR [Laird et al., 1987], [Laird, 2008], which implements symbolic and non-symbolic representations of knowledge, learning mechanisms and long-term memories. ACT-R is another cognitive architecture which is based in the assumption of the division of human knowledge in declarative and procedural representations [Anderson et al., 2004]. CLARION [Sun, 2002] is a cognitive architecture implemented with different subsystems: the action-centred subsystem to control *actions*; the non-action-centred subsystem to maintain general knowledge; the motivational subsystem to provide underlying motivations for perception, action and cognition; and the meta-cognitive subsystem to control the operations of the other subsystems. Other cognitive architectures are EPIC [Anderson and Matessa, 1997], 4CAPS [Just and Varma, 2007] and CHREST [Gobet and Lane, 2010]. With regard to the development of architectures that implement team cognition processes, some of these are COGNET [Zachary et al., 1992], GRATE* [Jennings, 1995], STEAM [Tambe, 1997], OAA [Martin et al., 1999], CAST [Yen et al., 2001], and Team-Soar [Kang, 2001] already mentioned in section 2.2.2.

Since the creativity concept has been mentioned as an important outcome from cognitive processes, it is useful also to mention that in very recent times some efforts have been devoted to the modelling and simulation of creative behaviours in artificial systems. Computational Creativity is the well known name of this new multidisciplinary endeavour and includes theories and advances from artificial intelligence, cognitive psychology, philosophy and the arts. In summary, Computational Creativity is the study of building software that exhibits behaviour that would be deemed creative in humans where this creative software can be used for autonomous creative tasks such as inventing mathematical theories, writing poems, painting pictures and composing music [Colton et al., 2009]. Some experiments have shown initial advances towards the development of this software applied for creating visual art [Ventura, 2008], automatic story generation [León and Gervás, 2008], [Pérez y Pérez and Sharples, 2001], music [Forth et al., 2008], [Alvarado and Pérez y Pérez, 2008], and language constructs [Veale and Ho, 2008].

Although there are still several open research questions in the modelling of human cognition and computational creativity, it is important to clarify that in the context of this thesis we are interested in how cognitive capabilities, and specifically the creative behaviour, influence human behaviour in work teams. In this sense, the cognitive attributes are modelled as *input* variables to get different behaviours (as it is explained in the following Chapter 3) and not as the final outcome from a model of mental processes.

2.3.2. Emotions

In the past, for many years the main belief was that emotions are an undesirable product of the human rational mind, and thus the less emotional a person was, the more intelligent and reasonable he/she was. This point of view might have its roots in the Platonic notion that feelings were the *enemy* of reason and that *citizens would do all they could to banish emotion from their day-to-day "cognitive" decisions* (see *The Republic* by Plato). Nevertheless, in recent years some researchers have probed that emotions are a relevant part of the human reasoning and are necessary for an *intelligent behaviour* [Damasio, 1994], [Gray et al., 2002].

One of the most important research experiments that proves the relevance of emotions in the human rational thinking mechanism was developed by the neuroscientist Antonio Damasio [Damasio, 1994], who studied and reported the behaviour of some experiments with people with brain damage. In concrete, Damasio's presents the case of one of his patients called Elliot, who had a brain tumour just behind the forehead that was successfully extracted with a surgical intervention. After that intervention, Elliot's personality changed. Elliot was a brilliant lawyer, and despite his intelligence was not altered (his IQ tests could not find any problem with his mental ability) he wasted his time in insignificant details as if he had lost the ability to prioritise. Damasio noticed that although Elliot's memory, attention, logic capacity and other cognitive abilities were intact, he could not feel anything with respect to events that were happening to him. Elliot could talk about the most tragic events of his life with a completely absence of emotions as he was an external viewer. Damasio's opinion was that brain intervention was the cause of Elliot's behaviour and he was right because some connections between the emotional brain and the cerebral cortex were sectioned in the operation. Therefore, Elliot thinking brain worked correctly but he was unable to make decisions, as he could not set values to different alternatives to prioritise them and select one. The absence of feelings was the cause of a faulty reasoning mechanism.

In the context of human behaviour at work, the influence of emotions is also recognised of great importance. The clearest example of this importance is the development of the relatively *new* concept of *Emotional Intelligence* [Mayer and Salovey, 1997], [Goleman, 1995]. Emotional Intelligence is defined as a multifactor individual difference variable to meet the traditional standards of intelligence [Mayer et al., 1999]. More specifically, [Mayer et al., 1999] state that Emotional Intelligence is composed of four abilities: (1) the ability to identify one's own and others' emotions to accurately express own emotions to others; (2) understanding how emotions orient people toward important information and how different emotional states can induce varying approaches to problem solving; (3) understanding the meaning, progressions, and complexity among emotions; and (4) the ability to stay open to feelings, to detach, and to manage one's own and others' emotions promoting emotional and intellectual growth.

With regard to the influence of emotions within work teams performance, despite the fact that group researchers have long acknowledge the importance of group's emotional life in its performance, there is relatively little research to date. Most of the studies have focused on individual level issues to show a positive relationship between emotional expression and organisational commitment [Allen and Meyer, 1990]; a positive relationship between emotions and work motivation [George and Brief, 1996] and the different types of emotions that can be experienced at work [Rafaeli and Sutton, 1989]. Some others have focused on the evaluation of the effects of mood (different than emotions) in work team performance [Kelly and Spoor, 2007], [Jordan et al., 2006] and only few studies have reported how emotions influence directly (e.g. envy in work teams [Duffy and Shaw, 2000]) or indirectly (e.g. analysing the role of emotions in conflict management within work teams [Desivilya and Yagil, 2004]) the work team performance.

Most of these research studies on the influence of emotions at work have their theoretical roots (equally as cognitive research) on Psychology, the discipline that has put forward several ideas about the processes of emotion in humans trying to explain the human emotional behaviour. Different psychological theories and models have been developed addressing different conceptualisations of emotions [Davidson et al., 2003], [Dagleish and Power, 1999] and for different purposes [Martin and Clore, 2001], [Forgas, 2000]. A good review of some of these theories and models is presented in [Scherer, 2000] where a classification of the existent models is proposed according on different components of the emotion process.

From the existent psychological theories, the cognitive appraisal theories focus on the elicitation of emotional experiences as result from constant evaluations of the subjective significance of construed situations and events, according to specific dimensions or criteria [Ortony et al., 1988], [Rosemann and Smith, 2001], [Scherer et al., 2001]. The key characteristic of these theories is that the emotional process is seen as the permanent assessment of the environment according to the person's goals, intentions and standards, i.e. appraisal. When the person appraises a specific situation in the environment to be of positive or negative importance, this does however not lead to a direct response. Appraisal triggers first a motivation for possible a further action, commonly known as action tendency [Rank, 2009]. Changes in the environment that are deemed to be of subjective importance for the observer are addressed by proposing lines of reaction that, at the end, will form the behaviour.

Due that cognitive appraisal theories are focused on emotion as a process rather than in the descriptive characterisations of emotions in dimensional or categorical models, several works in modelling human behaviour are based on these theories. One of the most influential theories for implementation in artificial systems has been the often referred as the OCC (Ortony, Clore and Collins) model [Ortony et al., 1988]. In summary, the OCC model relates types of emotional reactions to types of emotional responses. The model includes what can be subject of appraisal and according to what it may be appraised. An individual can have positive or negative reactions to a specific situation depending on how the object of the appraisal (an event, and action of somebody or an actual object) is relevant to the individual's goals, to the standards it tries to uphold, or to its tastes. Then, to be able to process its situation in such manner, the individual needs to have goals, standards and tastes. The OCC model is used as the theoretical basis in several applications, and more deeply referred to model an intelligent and believable behaviour in synthetic characters [Taihua et al., 2007], [Krenn, 2003], [Bartneck, 2002], [Andre et al., 2000], [El-Nasr et al., 2000].

The above mentioned studies are only small evidence about the increasing interest in the study and modelling of emotions (a deeper analysis can be found in [Martínez-Miranda and Aldea, 2005]). It is clear the high importance that the emotional behaviour has on the global human behaviour and the modelling of it in artificial systems has originated great efforts such as the development of new research branches (e.g. Affective Computing [Picard, 1997]) and large research associations (e.g. HUMAINE[1]).

2.3.3. Personality Traits

Other of the psychology branches that have dedicated big efforts, since long time ago, to the study of human behaviour based on the identification and classification of individual differences is Personality Psychology [Carducci, 2009]. Personality is a concept very well studied for many scientists since the 1950s and several different definitions based on different theories have been proposed.

The different theories of personality explain the same patterns of behaviour from different perspectives. Some of these theories of personality include the *biological perspective* where personality focuses on biological processes (such as genetic makeup, hormonal factors, physiological arousal and brain chemistry) operating within the individual [Eysenck, 2006]. The *evolutionary perspective* attempts to understand the individual differences as an adaptation to environment changes and challenges [Buss, 2008], [Wilson, 1975]. The *behavioural* perspective, as introduced in the above section 2.3.1, explains that individual differences and behaviour are caused by the environment. The

[1] See http://emotion-research.net/

cultural perspective proposes that individual personalities, broader correlations and generalizations can be made about the specific culture of the individual [Wallace, 1970]. The *social cognitive* perspective explains that behaviour is guided by cognitive processes (e.g. expectations) about the world and about other people [Bandura, 2001].

Due to the different theories of personality, there is not a consensus in the definition of the concept, but the different definitions of personality have some common features. In [Carducci, 2009], the following shared features are presented jointly with the current research interests related to each characteristic:

- *Uniqueness of the Individual:* each person is different. *Research issues*: What is the nature of this uniqueness? (e.g., unique combinations of traits or genes or different learning histories)?

- *Uniformity of Behaviour:* behaviour of the individual is consistent over time and across situations. *Research issues*: To what extent do situational and personality factors interact to determine our behaviour?

- *Content and processes:* personality consists of something that influences behaviour. *Research issues*: How our expectations in one situation influence our behaviour in others?

The different theories of personality have originated different models containing various dimensions to assess the distinct (but consistent) styles of behaviour. Even in the ancient Greece, Hippocrates (460-370 BC) classified four types of *humors* in people: *Choleric, Melancholic, Sanguine* and *Phlegmatic*. More recently, in 1923 Carl Jung [Jung, 1971] proposed two types of *attitudes* in people *Extraversion* and *Introversion,* which modify the four Jung's proposed functions of consciousness: *perceiving* (*Sensation* and *Intuition*) and *judging* (*Thinking* and *Feeling*). The well-known Myers–Briggs Type Indicator (MBTI) of personality is based on Jung's theory [Myers, 1995]. Other model of personality was proposed by Hans Eysenck [Eysenck, 2006] based on the biological perspective of personality. The Eysenck's model, known as the P-E-N model, initially includes two dimensions of personality: *Extraversion* and

Neuroticism, adding afterwards the third *Psychoticism* dimension.

Probably the most accepted (but not exempt of criticism) personality model is the *Big Five* model [Goldberg, 1993]. This model is the final result of the work developed over three or four decades of research, where five broad factors were gradually discovered and defined by several independent sets of researchers [Digman, 1990]. These five big factors of personality (also known as the OCEAN model) are *Openness* (which involves active imagination, aesthetic sensitivity, attentiveness to inner feelings, preference for variety, and intellectual curiosity), *Conscientiousness* (which includes elements such as self-discipline, carefulness, thoroughness, organization, deliberation -the tendency to think carefully before acting-, and need for achievement), *Extroversion* (which is characterised by positive emotions, tendency to seek out stimulation and the company of others), *Agreeableness* (which includes the tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others), and *Neuroticism* (sometimes called *emotional instability,* includes the tendency to experience negative emotions, such as *anger* or *anxiety* and to interpret ordinary situations as threatening, and minor frustrations as hopelessly difficult).

Most of these personality models are helpful as a conceptual and organising framework and try to explain the different patterns of behaviour at a high level. Some studies have proved that in predicting actual behaviour the more numerous facet or primary level traits the more effective [Paunonen and Ashton, 2001], [Mershon and Gorsuch, 1988]. In the context of human behaviour at work, [Merrill and Reid, 1999] have focused on the identification of the personal styles that affect the job performance and relationships. They propose four styles or patterns of behaviour at work: *Amiable, the Relationship specialist; Analytical, the Technical specialist; Driver, the Command specialist;* and *Expressive, the Social specialist*. According to [Merrill and Reid, 1999], each particular style could have its own strengths and weaknesses over the performance, and the important challenge to managers is to identify how people with different styles can work together and how to best handle themselves and the employees.

Complementarily, some other studies use the results from the Personality Psychology to analyse how the different personality traits influence and predict the job performance in concrete occupations [Code and Langdan-Fox, 2001], [Heller et al., 2002], [Naquin and Holton, 2002]. One examples is presented in [Tracey et al., 2007], where a study shows that *conscientiousness* is a good predictor of job performance for experienced employees in the line-level of a restaurant; a consistent result with the findings presented in [Hurtz and Donovan, 2000], which suggest that this personality trait (conscientiousness) is the most predictive of job performance.

Regarding the influence of the personality traits within work teams, several studies have been developed to relate the different traits of personality with the team performance. A study developed with an engineering team found that team members who possess high level of *conscientiousness* manifested increased task performance, while those with minimum composite level of *extraversion* are highly successful in managing product design processes. However, it was shown that *openness* to experience insignificantly influences team efficiency [Kichuk and Wiesner, 1997]. More recently, other study presented in [Lim and Ployhart, 2004] found that in 39 military combat teams *neuroticism* and *agreeableness* were negatively related to transformational leadership[2] ratings. An additional study was done using a team of students working on an engineering assignment to assess the individual satisfaction with the team [Peeters et al., 2006], reporting that satisfaction with the team is negatively related to dissimilarity to the other team members only for members low in *extraversion*. A different study was developed using 78 college students working in 10 long-standing teams competing in a business simulation, finding that emotional stability (the opposite trait of *neuroticism*) predicted task performance and *agreeableness* predicted cohesion within the work team [O'Neill and Kline, 2008].

[2] Transformational leadership is defined as *leadership that creates valuable and positive change in the followers* [Burns, 1978].

It can be argued that the results obtained from the different studies largely depend on the types of activities of each work team, but it is unquestionable that the personality traits are another important factor that directs the behaviour of a person. Due to this fact, the interest to include models of personality into artificial systems has increased in the last years (just as with the emotions) to reproduce more realistic human behaviours. In fact, one of the authors of the OCC emotional model argues that the modelling of emotional synthetic characters should incorporate personality, *not to be cute, but as a generative engine that contributes to coherence, consistency, and predictability (i.e. believability) in emotional reactions and responses* [Ortony 2003].

It is precisely in the development of synthetic characters (more commonly known as *virtual characters*) where theories of personality psychology are applied to direct the behaviour of these artificial entities. For example, the Virtual Theatre Project at the University of Stanford is one of the works that used personality traits to direct the behaviours in a Cybercafé scenario, where virtual entities can interact with users [Rousseau, 1996]. More recently, virtual characters with personality have been used for pedagogical purposes [Martínez-Miranda et al., 2008], the simulation of bargaining in e-commerce [Nassiri-Mofakham et al., 2008], and the generation of faces displaying emotions and moods according to the personality traits [Arellano et al., 2008], and entertainment [Campano and Sabouret, 2009], among others.

A complementary research has been developed to evaluate the believability and consistency achieved in the behaviour of virtual characters when using personality [Isbister and Nass, 2000], finding higher preferences from users when interacting with *consistent* characters and with identified personality traits [Berry et al, 2005], [Lee and Nass, 2003]. All these findings, complemented with the studies that prove the helpfulness of personality traits as predictors of work performance, have put the roots of this thesis to simulate human behaviour in work teams, as it is explained in the next Chapter.

2.3.4. Social-related Factors

Additional relevant factors that directly affect human behaviour are the actions and behaviours of the people with whom the individual interact. This is especially important when talking about work teams due to the relevance that human relations have to achieve teamworking behaviours (such as good communication and co-ordination among the team members) and are the foundation of *healthy and productive work environments* [Pyoria, 2005]. The study of the *social* factors that influence human behaviour is the main objective of Social Psychology, which is focused on the understanding of *how people's thoughts, feelings and behaviours are influenced by the actual, imagined of implied presence of other human beings* [Allport, 1985].

From the Social Psychology perspective, the individual human behaviour is studied by trying to understand its nature and causes in social situations, and it is looked as influenced by other people and the context in which this occurs [Brown, 2006]. Different topics are studied and analysed as important influences in human behaviour, including the understanding of *the self, social cognition, attribution theory, social influence, group processes, prejudice and discrimination, interpersonal processes, aggression and prosocial behaviour.*

Although all of these factors are relevant as important sources of social influence on human behaviour, the topic that better describes the social dynamics of human behaviour within work teams is the so called *group processes*. According to [Johnson and Johnson, 1987], a social group is a collection of individuals who: *interact; see themselves as a group; are interdependent and interact with each other; are trying to achieve a shared goal; follow a common set of norms/roles*. Therefore when a person is member of a group, his/her individual behaviour could be affected negatively or positively as consequence of this membership.

On one hand, individual performance may decrease when working in a group rather than alone, emerging the *social loafing* effect. According to [Geen, 1991] social loafing may emerge in a group due to different reasons, including: *i) output equity* defined as when the person *believes* that efforts are decreased in groups and that others in the group also believe this, therefore to maintain equal output they also engage in such behaviour; *ii) evaluation apprehension:* although there is more anxiety about being evaluated as an individual, within a group people believe that they are more anonymous and thus feel that they do not have to make much effort if unmotivated; and *matching to standard*: in the absence of a clearly defined goal, or standard to match, people tend to apply less effort. Also, according to [Brown, 2006] the group size may also influence the performance of the individual: greater the size of the group, more diffused the sense of responsibility.

On the other hand, individual performance may also be increased within a group due to the *social compensation:* when a person believes that others will decrease their efforts in a group and so the individual compensate for this by working harder. Then it is therefore possible that groups work collectively harder than the sum of its individuals [Brown, 2006]. Additionally, the *cohesion* of a group jointly with *group's norms* fostering higher productivity, also influence in a positive way the individual and collective performance [Brown, 2000].

One of the important factors behind group's cohesion and dealt by social psychologists for more than 40 years is the notion of *trust*. The concept of trust has been especially discussed during the last decade, mainly from an Organisational perspective [Das and Teng, 1988], [Elangovan and Shapiro, 1998]. This increasing interest in trust within organisations could be explained as there are more and more large companies and consortiums where several people need to work together from different geographically locations. New theories and hypotheses about the thinking and functioning of organisations have been replacing traditional aspects of management by collaborative approaches emphasising ideas of coordination, sharing of responsibilities and risk taking [Vangen and Huxam, 2003], [Costa and Peiró, 2009].

Trust is also frequently espoused as being critical to effective team processes and performance [Dirks, 1999], [Costa, 2003]. One of the arguments that supports the importance of trust in work teams is that team members who trust each other are better able to examine and improve team processes and hence, to self-manage their own performance [Larson and LaFasto, 1989]. Also, [Jones and Shapiro, 2000]; [LaFasto and Larson, 2001] argue that employees report that lack of trust is one reason why they resist the introduction of teams in the first place; and that its absence interferes with the effective functioning of work teams in the second instance.

The analysis of trust within work teams has been addressed from different perspectives. The study presented in [Costa et al., 2009] found that in 79 project-research teams, high levels of trust were achieved throughout the project if the team members have previously worked together or are acquainted/friends among them. On the contrary, those teams composed of members that have no previous history in working together, present lower levels of trust in the different stages of the project. Additionally, the authors also found a positive relation between high levels of trust and more cooperative behaviour, which in turn also contributes to a better team performance.

Other studies have also stressed the influence and importance of trust on work teams' performance according to the particularities of those work teams. For example, in [van der Zee et al., 2009], the authors focused on the analysis of demographically diverse work teams and present a review of different social-identity patterns as antecedents of trust and their implications for organisations. The authors indicate that a social-identity pattern based on creating an overarching group identity rooted in similarities may stimulate subgroup identity and thus fragment the group. They suggest the promotion of a relational identity orientation or the creation of a common identity based on respect for differences and the appreciation of such differences as an asset for the whole group and for the organization. According to the authors, a relational orientation then may promote good levels of trust in partners from different cultural backgrounds.

Additional studies have concentrated efforts on the analysis of trust in other particular type of teams: virtual work teams which are characterised by the fact that their members work together on a mutual goal but interacting from different locations and, therefore, communicate and cooperate by means of information and communication technology [Bell and Kozlowski, 2002]. Although virtual teams provide several advantages, there are also some problems such as those mentioned in [Gattiker et al., 2001], describing that *the* *more virtual the behaviour of a team, the fewer opportunities individuals have to develop relational ties and bonding social capital* (e.g. the development of good levels of trust). In this context, a study presented in [Zornoza et al., 2009] shows that trust climate moderates the relationship between the *virtuality level* (based on the characteristics of the used technology such as videoconference or computer-mediated communication) and team process satisfaction and team cohesion when the virtuality level is high. A different study is presented in [Rico et al., 2009] showing the importance of different types of communication in virtual teams (i.e. task-oriented and socially oriented communication, and enthusiasm) and their predictability for trust climate development and growth through different stages of the project.

In the context of Computer Science and with the great development of applications in Internet, the interest in the study of trust has grown up [Bierhoff and Vornefeld, 2004] and some research works put efforts towards the modelling of trust and reputation concepts addressed mainly to e-Commerce applications [Sabater and Sierra, 2001], [Yu and Singh, 2002]. Most of these models of trust and reputation use software agents as the entities where the relationship of trust takes place and is represented using specific characteristics of each different model [Sabater and Sierra, 2005].

A complementary computational approach is the modelling of trust in social simulations. For example, the work presented in [Kim, 2009] describes an agent-based social simulation model of a supply network where trust is modelled in the agents' behavioural decision-makings to examine the intermediate self-organisation processes and the resulting macro-level system behaviours. The results reported by the author show that agents' decision-making behaviour based on a trust relationship in two trading agents can contribute to the reduction in the variability of inventory levels. The author explains that the results show the fact that mutual trust relationship based on past experiences of trading diminishes an agent's uncertainties about the trustworthiness of its trading partners and thereby tends to stabilize its inventory levels. Similarly, [Tykhonov et al., 2008] presents an agent-based simulation model to analyse the effect of individual decision making in partner selection, negotiation, mislead and trust on system behaviour in the context of supply chains and networks.

Other works have also used models of trust to analyse and improve different types of relationships and interactions such as those between clients and wealth managers [Thompson and Bossomaier, 2006], those developed in virtual organisations [Patel, 2006], online auction systems [Patel et al., 2007] and even to improve the algorithms used in sensor networks [Matei et al., 2009].

2.4. Summary

The understanding of human behaviour, its antecedents and consequences is one of the topics that has been studied for ages and from different perspectives. Although human behaviour can be considered by *nature* an unpredictable and complex phenomenon, in the last decades several efforts have been dedicated towards the development of computational models aiming to simulate specific characteristics of human behaviour under specific contexts. This chapter presents an overview of the different initiatives towards this end, emphasising the context of human behaviour within work teams. The chapter first rationalises the usefulness of models of human behaviour by explaining the goals, advantages and applications of this kind of models. After that, a brief review of the most used techniques in the modelling of human behaviour is presented putting particular emphasis in the agent-based modelling.

After present the *why* and the *how* in the modelling human behaviour, this chapter concentrates in the *what,* by presenting a selected set of human characteristics that can be and are already included in existent computational models of human behaviour. Four main human attributes are presented as important factors that influence, produce and direct human behaviour in the context of work teams: *cognition, emotions*, *personality traits* and *social-related* factors. This set of attributes is not, of course, the complete spectrum that directs the human behaviour but it is, at least, an important part of the complete picture and allows the study and understanding of work team dynamics. The rationale behind the selection of these human attributes is explained through the description of different (mainly) psychological research works that justify the importance of each of these human characteristics in the generation of human behaviour putting especial attention in the context of groups and teams. Additionally, an overview of current computational models that include one or more of the selected human attributes developed for different approaches and specific purposes is also presented.

As a conclusion, it can be argued that the modelling and simulation of human behaviour in artificial systems is possible and useful as long as the human attributes behind the behaviour are correctly selected according to the particular and specific characteristics of the context where human behaviour needs to be studied, analysed and understood.

Chapter 3

TEAKS: Modelling the Team Members and the Team Project

We often fail to realise how little we know about a thing until we attempt to simulate it on a computer
Donald Knuth (1968).

3.1. Introduction

In our current world of global economy where innovation and competitiveness are key factors to increase the success of (public and private) organisations, most of these organisations are turning to new, more adaptive ways of doing their work such as flatter organisational structures, more team-oriented environments, and greater support from technology. This implies that higher organisational performance is being gained from empowered individuals working together and contributing with the best of their knowledge, skills, and capabilities. When considering these new ways to organise the work, it is not surprising to find that organisations have a high reliance on work teams. This argument is reinforced by empirical studies such as the one presented in [Trent, 2003a] where the analysis over 172 US manufacturing firms concluded that the use of teams remains a popular and growing design option among firms.

Nevertheless, the use of work teams by itself does not guarantee a greater organisational effectiveness, and although teams can accomplish much that is good, they can also do a *great harm* [Likert, 1961]. Even worst, work teams can enforce lower performance norms, create destructive conflicts within and between teams, and also they can exploit, stress and frustrate their members – sometimes all at the same time [Hackman, 1987]. The critical point between getting *good* or *bad* work teams is the careful planning by team builders to ensure that the reality of using teams matches the expectations surrounding their use [Trent, 2003b]. As [Trent, 2003b] suggests, from all the team planning activities, the selection of members is perhaps the most critical task. One key decision is to define the size of the team, that should include just enough members to accomplish their tasks but no more than can be effectively managed [Hackman, 1987].

During the selection of the team candidates, the potential team members should satisfy a number of criteria such as to have the knowledge and the experience that is relevant to the work activities to perform. Ideally, the candidates should also demonstrate a level of interpersonal skills that enable them to interact with other individuals within the team. The decision about who would form the team should take place after identifying the skills and abilities that the project to be performed requires, but in many cases the member selection is often made by convenience and people availability rather than objective assessment, increasing the possibility that the final work team configuration is unqualified or incompatible [Trent, 2003b].

It is in this context where the work developed in this thesis aims to contribute by supporting the selection of suitable candidates to form a work team through a simulation tool for the analysis of the team's collective behaviour from the individual characteristics of the candidates. The development of such a tool needs in a first step, the development of a model that includes the relevant components of the phenomenon under analysis. This chapter introduces the TEAKS (TEAm Knowledge-based Structuring) model by describing its two main components: the modelling of the team candidates as software agents and the modelling of the work project as a finite set of interdependent tasks.

3.2. TEAKS General Architecture

When we refer to the word *team*, one can find several definitions due that the term is usually associated with an enormous variety of social and organisational concepts. Thus, a delimitation of the term is necessary to understand what *work teams* mean in the context of the present research. We adopt the definition of team as *an interdependent collection of individuals who work together towards a common goal and who share responsibility for specific outcomes of* *their organisations* [Sundstrom et al., 1990]. This definition implies that individuals adopt the *goal* and the *commitment* toward the correct development of the assigned work activities. Complementary, the term *work* is defined as *the occasion for a team to come together* and *working* is the principal activity connecting members to each other and the team to its environment [Hackman, 1987]. This definition emphasises the collective performance and the factors that determine it.

Using this definition of *work team*, TEAKS is developed as an agent-based model where software agents are designed to simulate the interaction between the represented team candidates in the context of a specific project, with a concrete assignment of tasks. The execution of simulations of the work team model will provide statistical information about the individuals and whole team performance.

The overall process will consider different work team configurations that can be used for performance comparison. It consists of several steps (see Figure 3.1):

- **Work team initial configuration.** In a first step, the internal state of each agent is configured with the attributes of the real candidate that the agent represents. The values of each attribute could be obtained from existent cognitive and psychological standardised tests. Additionally, the representation of the project in which the work team will work is also configured at this step by setting up the particular characteristics of each project task. The relationship between the agents and the project is set up by the assignment of each task of the project to one or more agents. This entire configuration will be the input to the next step where the simulation takes place.

- **Execution of the simulations.** This process is based on the simulation of the interaction among the agents and the project to get the estimation of the work team performance. During this step, the configuration of the team can be changed to analyse whether the changes improve or diminish the global performance of the work team. That means that new agents with different internal states can be added to the team, some can be removed, or new assignments of tasks can be made. Once these modifications are introduced, new simulations can be executed to analyse the consequences and observe which team presents a better performance.

- **Proposed work team final configuration.** The team with the best performance is taken into account in order to get the information related to each team-member performance, which will be used by the project manager for the configuration of the real work team.

In this three-step process, the important factor is the representation of the real candidates as software agents. The selected set of human attributes used in the TEAKS model is described in the following section.

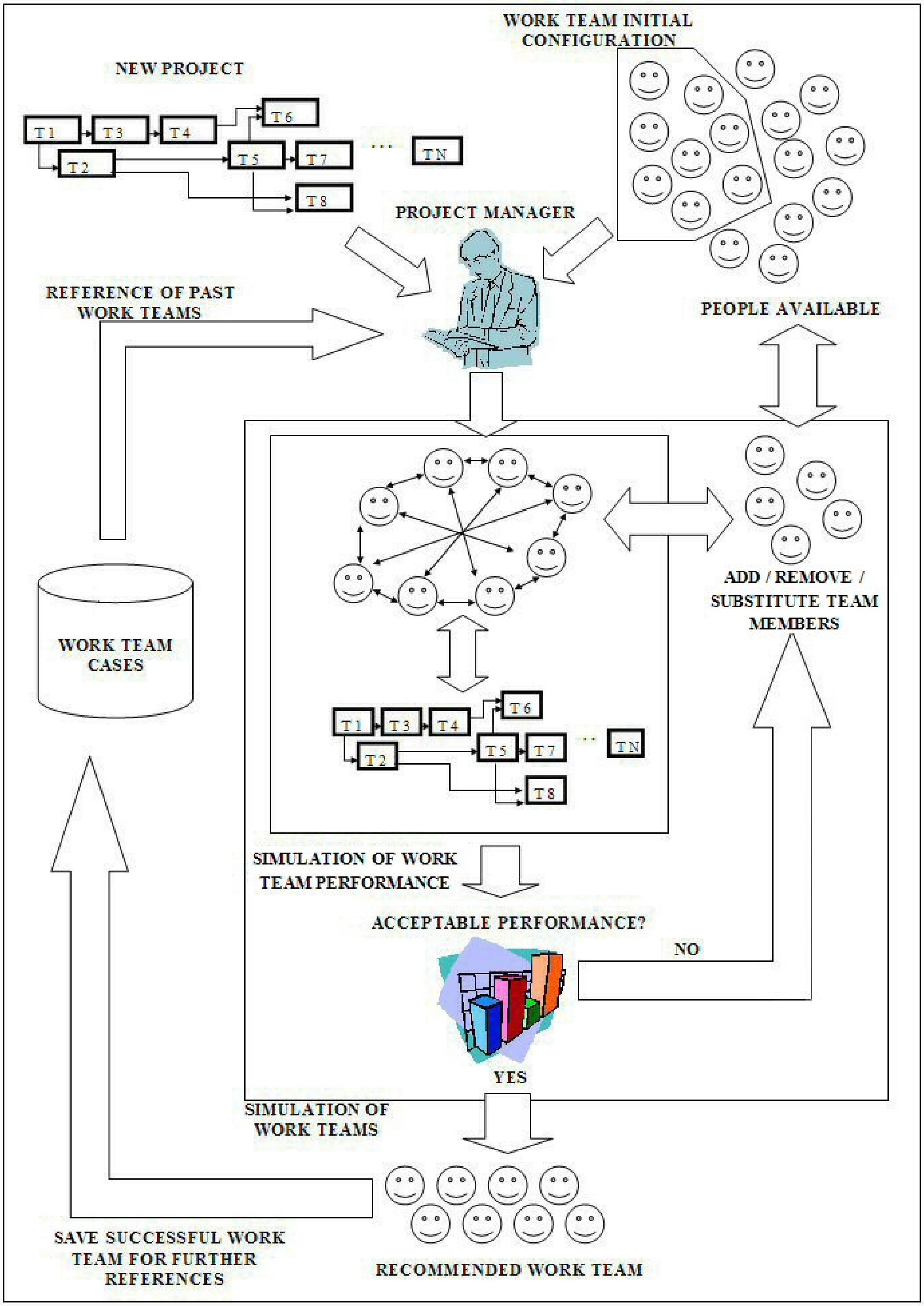

Figure 3.1. General Architecture of TEAKS.

3.3. Modelling the Human Attributes Inside the Team Members

In the existent agent-based models of work teams presented in Chapter 2 - section 2.2.2 ([Marreiros et al., 2005], [Marreiros et al., 2006], [Dong et al., 2008] and [Rojas and Giachetti, 2009]), the individual characteristics modelled in the agents that represent real team members mainly focus on cognitive-related capabilities (such as *the level of experience*, *the training level*, *technical skills,* the *learning ability*, *decision-making* and *area of expertise*) and social-related factors (such as *social skills* and *communication capabilities*). Only [Marreiros et al., 2006] includes an emotional component in the internal model of the agents, but there is not a clear description about the influence of emotions in the work team performance.

In the TEAKS model, the internal state of the team members is modelled through the structure shown in Figure 3.2. The structure of the agent's internal state basically contains four attributes:

1. Cognitive-related capabilities
2. Emotional state
3. Personality
4. Social-related skills

As it was introduced in Chapter 2, each one of the four attributes is an important factor that affects human behaviour while executing work activities as part of a team. For each one of the four attributes a set of variables was selected as it is described in the following subsections.

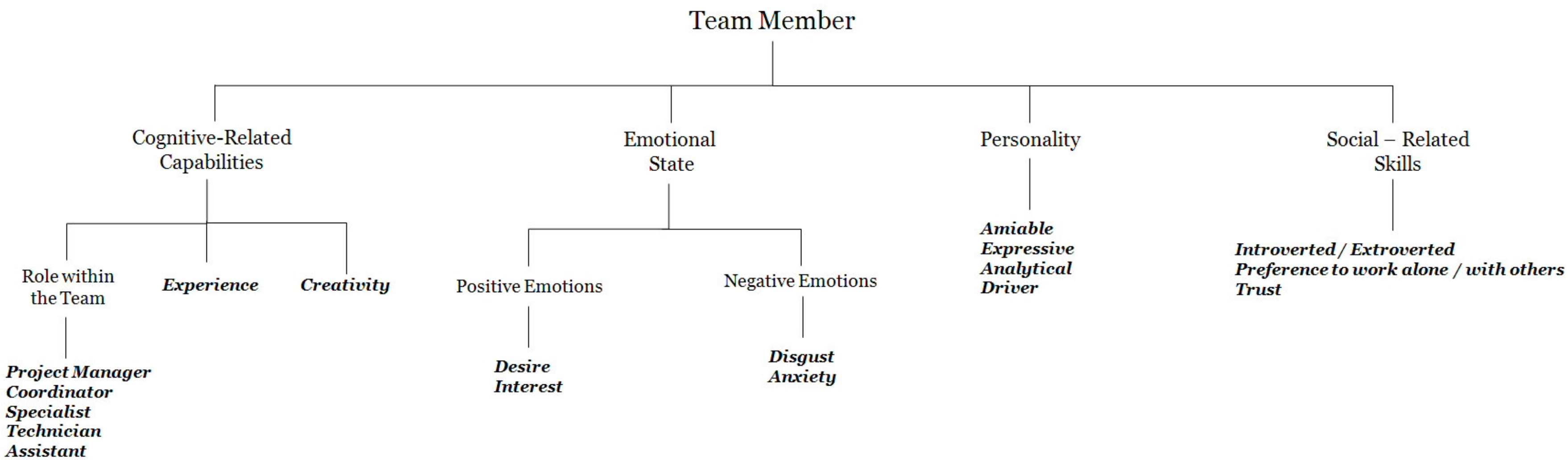

Figure 3.2. Internal state structure of the team members in TEAKS.

3.3.1. Cognitive-Related Capabilities

As it was introduced in Chapter 2, quite often cognitive capabilities are the main considered factors to select a person for a technical job facilitated by the several tests to measure the IQ in a person. Human cognitive capabilities involve several brain processes such as *perception*, *memory, introspection, imagination* and *reasoning* among others. Modelling these brain processes and their interactions to generate an intelligent behaviour has been one of the main goals of Artificial Intelligence and it is clearly out of the scope of this thesis. Nevertheless, to model cognitive-related factors representing the *purely technical skills* of a person within a work team we have selected five general team roles that can take place in any work team. These roles represent the personal degree of expertise in the tasks that the work team must to perform. The five roles that were identified are:

- ***Project manager.*** This role represents the team member in charge of managing the project and assigning tasks to the other team-members.
- ***Coordinator.*** The coordinator role represents the person in charge of specialised tasks, re-configuration of tasks and re-allocation of resources.
- ***Specialist.*** This role represents the person in charge of complex and specialised tasks, for example Chemical Engineers, Environmental Engineers, Software Engineers, etc.
- ***Technician.*** The technician represents the person who can deal with technical and no-specialised tasks.
- ***Assistant.*** Represents the person in charge of not complex, routine and repetitive tasks.

During the initial configuration of the simulated work team, any of these roles can be selected according to the technical knowledge of the real candidates. Additionally, each team-member has other two cognitive-related capabilities and that are role-independent. The first of them is the ***level of creativity*** that has been explained in Chapter 2, a creative behaviour is a key factor to increase the success in the work performance of an individual [Feneuille, 1997].

The second cognitive-related capability modelled in TEAKS is the ***level of experience*** and it represents the *much* or *none* experience that every team member has on the type of tasks that have assigned. The introduction of this variable is supported by several studies that show the important effect of work experience and job performance [Dokko et al., 2009], [Kolz et al., 1998], [Quiñones et al., 1995], [Avolio et al., 1990], [Sneed et al., 1987]. More specifically, the experience of a team member that is considered in TEAKS is at the *level of task*, i.e. how much experienced is the team member in the development of related/similar tasks to those that has currently being assigned. This is consistent with some studies that show that the relationship between experience and job performance is significantly higher when experience is defined at the task (rather than the job or organisational) level [Quiñones et al., 1995], [Dokko et al., 2009].

3.3.2. Emotional State

Many times the terms affect, mood, and emotion are used interchangeably throughout much of the literature, without distinguishing between them [Batson et al., 1992]. Some of the confusion or lack of clarity may be a result of the overlap among the concepts. Nevertheless, some researchers have attempted to distinguish these concepts based on structural differences and functional differences. Schwarz and Clore [Schwarz and Clore, 1988] differentiated emotion from mood based on structural differences, such as the specificity of the targets (e.g., emotions are specific and intense and are a reaction to a particular event, whereas mood are diffuse and unfocused) and timing (e.g., emotions are caused by something more immediate in time than moods). Batson and colleagues (1992) differentiated mood, affect and emotion based on functional differences, like changes in value state (affect), beliefs about future affective states (mood), and the existence of a specific goal (emotion).

Based on these structural and functional differences, the emotional state of a team member is composed of a selected set of emotions rather than of specific moods or affective relationships. The particular events that produce the changes in the emotions and their intensity for each team-member are the particular characteristics of the assigned tasks and the personnel features of the other team-members whom have to interact with.

Once the importance of emotions has been recognised (see section 2.3.2), the key decision is the selection of those context-relevant emotions to model in the TEAKS agents. The first step was the review of some literature where the broad set of human emotions is explained. In several works one can find that many psychologists have claimed that certain emotions are more basic than others, often for very different reasons. Despite the disagreement about the primary emotions, the work in [Ortony and Turner, 1990] summarises the different proposals of basic emotions according to some authors and the main arguments in favour of their inclusion in this category (see Table 3.1).

From the extended psychology classification of the basic emotions, we have selected a set of four basic emotions to model the agents' emotional state. Two of them are emotions considered with a *positive* valence and the other two are considered as *negative* valence emotions. The term *valence* is commonly used in Psychology by emotion theorists to refer to the *positive* and *negative* character of an emotion and/or of its aspects (such as behaviour, affect, evaluation, faces, adaptive value, etc.). Particularly for the TEAKS model, the positive and negative consequences of the selected emotions are reflected over the team members' behaviour.

The *positive* emotions included in TEAKS are the ***desire*** and ***interest*** of the team member to develop a specific task in a specific moment. The *negative* emotions are the ***disgust*** and ***anxiety*** generated by a given task in specific moment. The selection of these basic emotions was made according to the context of application and thinking in the most common emotions produced by the activities of a person while developing work activities. In most of organisational projects it is more common that one specific task or activity arouses some positive emotions such as the *interest* or *desire* (to develop that task or activity) in a worker than the arousal of *happiness* or *joy* emotions (most commonly identified during personal life situations). On the other hand, the negative emotions *disgust* and *anxiety* provoked by specific work activities are more common than *fear*, *pain* or *sadness*. There are, of course, several cases or situations at work that could provoke these other emotions (such as dangerous or high risk tasks), but the TEAKS model focuses on organisational projects where these type of tasks do not frequently appear.

Author	Basic Emotions	Basis for Inclusion
Arnold	Anger, aversion, courage, desire, despair, fear, hate, hope, love, sadness	Relation to action tendencies
Ekman, Friesen and Ellsworth	Anger, disgust, fear, joy, sadness, surprise	Universal facial expressions
Frijda	***Desire***, happiness, ***interest***, surprise, wonder and sorrow	Forms of action readiness
Gray	Rage and terror, anxiety, joy	Hardwired
Izard	Anger, contempt, ***disgust***, distress, fear, guilt, interest, joy, shame, surprise	Hardwired
James	Fear, grief, love, rage	Bodily involvement
McDougall	Anger, disgust, elation, fear, subjection, tender-emotion, wonder	Relation to instincts
Mowrer	Pain, pleasure	Unlearned emotional states
Oatley and Johnson-Laird	Anger, disgust, ***anxiety***, happiness, sadness	Do not require propositional content
Panksepp	Expectancy, fear, rage, panic	Hardwired
Plutchik	Acceptance, anger, anticipation, disgust, joy, fear, sadness, surprise	Relation to adaptive biological processes
Tomkins	Anger, interest, contempt, disgust, distress, fear, joy, shame, surprise	Density of neural firing
Watson	Fear, love, rage	Hardwired
Weiner and Graham	Happiness, sadness	Attribution independent

Table 3.1. Different classification of basic emotions (taken from [Ortony and Turner, 1990]).

3.3.3. Personality

Similarly to the selection of specific emotions that form the internal state of the TEAKS agents, one of the existent models of personality was also selected. The model proposed in [Merrill and Reid, 1999] has been selected due mainly to the close relationship reported between the four *personality styles* and job performance in *any occupation*. The four personality styles that have been selected for the TEAKS model are:

- ***Amiable – the support specialist.*** People with an amiable personality work well with others and promote harmony. They work at a slow and easy pace, which tend to lend an air of relaxation to others in the group. They prefer an atmosphere that encourages close relationships.

- ***Expressive – the social specialist.*** People with an expressive personality work at a fast and spontaneous pace. They like to try the new and different, have happy spirits and can endure hardships and trials easier than other personality styles.

- ***Analytical – the technique specialist.*** The priority of analytical people is the job at hand and the process to achieve it. The analytical person does not like unpredictability and surprises. Under pressure, an analytical person will withdraw into its own world and avoid contact with the causes of their stress.

- ***Driver – the control specialist.*** The main priority of people under this personality style is the task in hand and the results achieved. Under pressure, people with this personality style will assert themselves strongly and dedicate strong efforts to fulfil the required objectives.

All four personality styles have well identified characteristics that affect the behaviour of people facing the activities/tasks while working and when interacting with co-workers (see Table 3.2). An important factor in favour of these personality styles is the fact that there are currently various standardised questionnaires that managers can use to identify de degree of membership of the work team candidates to each of the four styles. Thus, the information obtained from these questionnaires should be the support that project manager(s) will use for the initial work team configuration when executing the TEAKS simulation tool.

Amiable	***Expressive***
Emphasis: Steadiness; co-operating with others to carry out the tasks. **Pace:** Slow and easy; relaxed. **Priority:** Relationships. **Focus:** Getting acquainted and building trust. **Irritation:** Pushy, aggressive behaviour. **Speciality:** Support; "We're all in this together so let's work as a team".	**Emphasis:** Influencing others; forming alliances to accomplish results. **Pace:** Fast. **Priority:** Relationships. **Focus:** Interaction; dynamics of relationships. **Irritation:** Boring tasks and being alone. **Speciality:** Socialising; "Let me tell what happened to me…".
Analytical	***Driver***
Emphasis: Compliance; working with existing circumstances to promote quality in products and services. **Pace:** Slow; steady; methodical. **Priority:** The task **Focus:** The details; the process. **Irritation:** Surprise; unpredictability. **Speciality:** Processes; systems; "Can you provide documentation for your claims?"	**Emphasis:** Dominance; shaping the environment by overcoming opposition to accomplish the tasks. **Pace:** Fast. **Priority:** The task. **Focus:** Results. **Irritation:** Wasting time: 'touchy feel' behaviour that blocks action. **Speciality:** Being in control; "I want it done right and I want it done now."

Table 3.2. The four personality styles and their influences on the behaviour while working (taken from [Biegler et al., 1997]).

3.3.4. Social-Related Skills

As introduced in the section 2.3.4, in any group of people, human relations are important to achieve a good communication and co-ordination which are particularly important between the members of a work team. Therefore the inclusion of a set of social-related skills variables in the TEAKS agents has been also considered. The selected social-skill variables are:

- ***Introverted / Extroverted.*** One person can be predominantly concerned with his/her own thoughts more that the social relations with the others (introverted) or he/she can be an outgoing, socially confident person (extroverted).

- ***Preference to work alone / Preference to work with others.*** A person at work may prefer to work alone to develop a specific task(s) even when he/she is an extroverted person, and vice versa.

- ***Trust relationship.*** This variable represents the level of trust achieved between the team members along time throughout the simulated duration of the project.

All the three selected social skills are close related with the personality styles, and when the behaviour of the TEAKS agents is generated (see more details in the next Chapter 4), the three variables are highly influenced by the different personalities. Nevertheless, the separation between the personality styles and the three social-related skills is maintained to put emphasis in the influence of the interaction between the team-members over the individual behaviour as a complement to the personality reactions generated by the characteristics of the assigned tasks.

3.4. Modelling the Team Project

The second important aspect to represent in the TEAKS model is the environment of the agents. In this sense, the principal activity that connects the individuals with each other in a work team is the project that they have to perform together. Therefore the relevant aspect to include in the TEAKS model is the representation of the team project. The first step towards the modelling of the project is to have a clear definition that help in the understanding of how and which specific type of projects can be included to be analysed in the TEAKS model. For this purpose, we adopt the definition from the *Project Management Body of Knowledge (PMBOK)*, an IEEE standard[3] that is well accepted in Organisational and Project Management disciplines. The knowledge and practices described in the PMBOK are applicable to most projects most of the time, and there is widespread consensus about their value and usefulness.

A project in the PMBOK is defined in terms of its distinctive characteristics: *a project is a temporary endeavour undertaken to create a unique product or service* (PMBOK Guide-2000, p. 4). *Temporary* means that every project has a definite beginning and a definite end. The end of the project is reached when the project's objectives have been achieved, or when it becomes clear that the project objectives will not or cannot be met and the project is terminated.

[3] See http://standards.ieee.org/reading/ieee/std_public/description/se/1490-2003_desc.html

Temporary does not necessarily mean short in duration; many projects last for several years. In every case, however, the duration of a project is finite; projects are not ongoing efforts.

Unique means that the product or service is different in some particular way from all similar products or services. A product or service may be unique even if the category it belongs to is large. For example, many thousands of office buildings have been developed, but each individual facility is unique: different owner, different design, different location, and so on. The presence of repetitive elements does not change the fundamental uniqueness of the overall effort.

Any project, therefore, can be divided into a set of *finite* and *unique* tasks assigned to one or more members of a work team. The TEAKS model of a project is based in this division of tasks where each task is represented by the following characteristics:

- ***Task description.*** This parameter is used for identification purposes and it describes the concrete skills that the task requires (e.g. "Analysis and design of a databases" in a Software Engineering project).

- ***Number of participants.*** This variable represents the number of TEAKS agents assigned to the task.

- ***Estimated duration.*** Every task has an estimated duration from its starting point to the end. In TEAKS, this time period is measured in working days.

- ***Sequence of the tasks.*** The sequence in which the tasks are executed is important; there could be some tasks that must start when precedent task(s) are finished. Other tasks are completely independent and can be executed in parallel.

- ***Level of Difficulty.*** This variable represents how much complex a task could be.

- ***Type of task.*** The type of a task can be generic (representing that the task can be executed by non-specialised team members) or specialised task (representing that the task needs to be executed by the specialised team members).

- ***Expected quality of the task.*** This variable represents the acceptable level of quality in the task and it is used during the process where the work team is obtained (explained in the next Chapter 4).

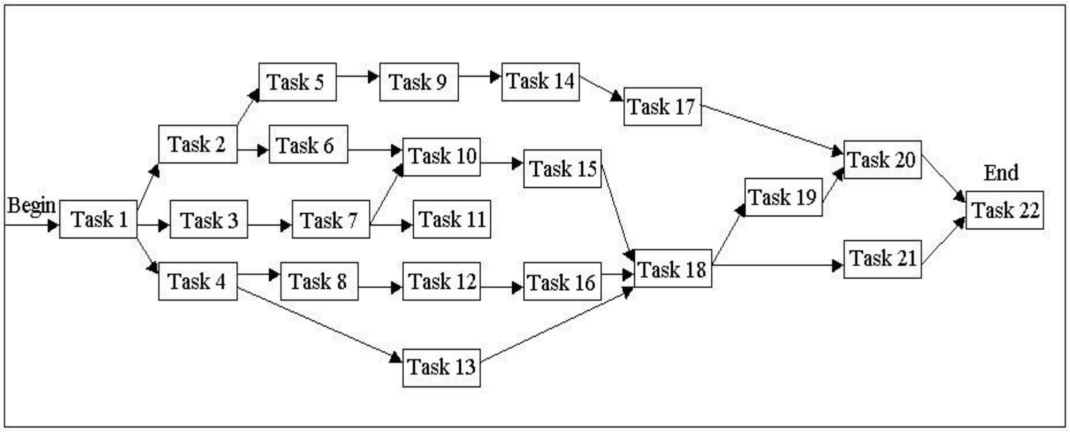

Figure 3.3. Graphical representation of a project with 22 tasks in TEAKS.

Needless to say that the division of the project into tasks, the sequence between them and the assignment of the tasks to the team members are some of the inputs for modelling the work team performance (as described in the section 3.2). Therefore the TEAKS model does not verify whether the planning of the project is correct or not, but offer the possibility to analyse the work team performance under different project configurations.

3.5. Defining the TEAKS Variables as Fuzzy Sets

When a model includes the representation of qualitative human attributes (such as those presented in sections 3.3.1–3.3.4), it is difficult to accept that a quantitative value could be used to measure any of these characteristics. It is more natural to say “this person is highly introverted” than “this person is introverted in 85%” or “I have a 30% of trust in my new colleague”. Thus when describing human attributes and relationships, most of the times the people tend to use words such as *low*, *medium* and *high*. For example we can say that a worker has a *high* level of experience, low *interest* in performing some specific activities, or that he/she is *highly* creative.

When a computational model has to deal with this type of *variables* one suitable method to represent their values is through the use of Fuzzy Logic [Zadeh, 1965]. In conventional logic, a statement is either true or false, with nothing in between. This principle of true or false was formulated by Aristotle some 2000 years ago as the Law of the Excluded Middle, and has dominated Western logic for centuries. Nevertheless, the idea that things must be either true or false is in many cases uncertain and the idea of gradations of truth is familiar to everyone when using some sentences as the aforementioned examples. Fuzzy logic offers a better way of representing reality by considering various degrees, ranging from *completely true* through *half-truth* to *completely false*.

Fuzzy Logic has been used in several applications for different purposes, typically in control [Lin, 2009], [Zimmermann, 2001] and some other research areas such as pattern recognition [Bailador and Treviño, 2010], case-based reasoning [Díaz et al., 2006], [Fdez-Riverola et al., 2005], image processing [Bigand and Colot, 2010], [Molina et al., 2003], data analysis [Sarkar, 2007] and Internet-based services [Aringhieri et al., 2006] among others. Within social sciences, fuzzy logic was first applied to the problem of social choice and self-organisation [Barnev, 1974], [Dimitrov, 1976]. More recently, the use of fuzzy logic with software agents (commonly known as *fuzzy agents*) has increased the interest of the research community and according to [Ghasem-Aghaee and Ören, 2003] fuzzy agents can be defined as *agents that can perform qualitative uncertainty reasoning with incomplete and fuzzy knowledge in some environment that contains linguistic variables*.

Fuzzy agents have been used in different applications such as autonomous mobile robots [Gómez-Skarmeta et al., 1999], computer vision [Asfaw et al., 2003], electronic commerce [Carbó et al., 2004], [Carbó et al., 2007] and improvement of teleconferences [Bobadilla and Mengual, 2004]. Some of these applications already include the use of fuzzy agents with models of human attributes. In [El-Nasr et al., 2000] a fuzzy-based model of emotions in agents where events and observations are mapped to emotional states is described. Similarly, the work described in [Ghasem-Aghaee and Ören, 2003] presents the development of fuzzy agents with dynamic personality for the simulation of human behaviour. Moreover, the use of fuzzy logic in agent-based models has also been applied to improve and make more realistic the representation of some of the attributes and relationships between agents [Carbó et al., 2005], [Hassan et al., 2008].

Due to the suitability in the use of fuzzy logic for the representation of qualitative and uncertain values, the modelling of the human attributes and some of the task attributes in TEAKS have been represented through the definition of specific fuzzy sets. For the *emotions, cognitive* and *social-related* attributes, three fuzzy sets were defined with a Gaussian membership function (see Figure 3.4). The range of values in these fuzzy sets ranges from 0 to 100 and from 0 to 1 in the *x* and *y* axes respectively. Axis *x* represents the different values that the attributes can get, and axis *y* represents the membership's degree of those attributes to each value. The first fuzzy set represents a *low intensity* where the range of values under the shape runs from 0 to 35. The second fuzzy set contains values from 25 to 75 representing a *medium intensity* in the corresponding attribute. Finally, the third fuzzy set with the range of values from 65 to 100 represents a *high intensity* in the agents' attributes.

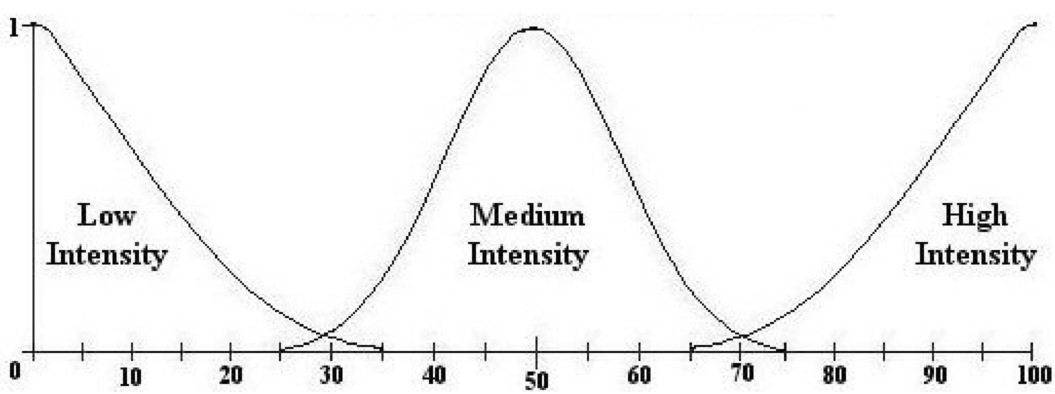

Figure 3.4. Fuzzy sets defined to represent the values for the emotional, cognitive and social-related attributes in the TEAKS agents.

The values defined in the three fuzzy sets allow linguistic labels for the attributes with different degrees of membership to each of the three values that, in the case of the emotions, can be increased or decreased throughout the simulated execution of the project. The possible increment/decrement in the values of the emotions depends on the specific characteristics of the environment, i.e., the characteristics of the other team members and the particularities of the assigned task(s) (this is explained in the next Chapter 4).

Similarly, three other fuzzy sets were also defined to represent the values in the personality styles. The use of fuzzy sets for the personality styles allows that a team member can be configured with different degrees of membership to the four personality styles, been the *dominant (*i.e. the representative*)* personality the style with the *higher* value. This is consistent with the existent tests of personality that define the style of a person from the different levels obtained in each personality trait, indicating for example, *how much* amiable/expressive/analytical/driver the person is. The fuzzy sets defined for the TEAKS model that represent the personality styles are shown in Figure 3.5.

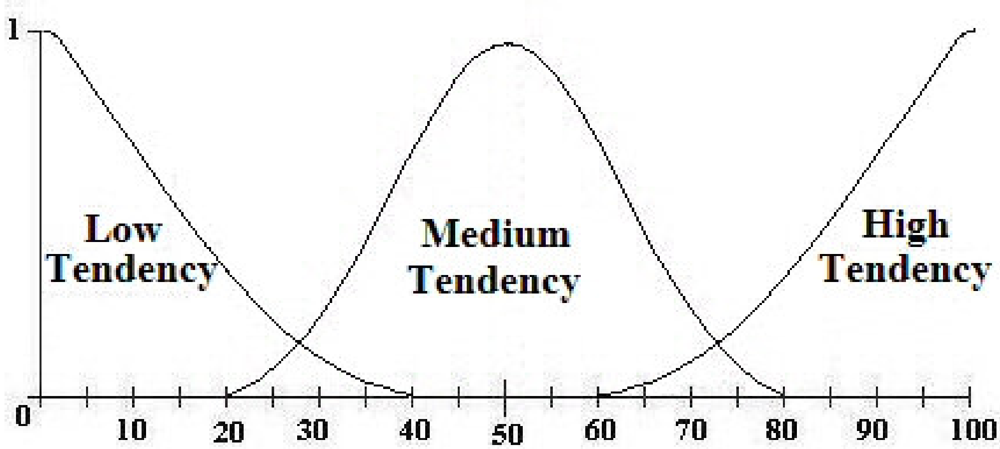

Figure 3.5. Fuzzy sets defined to represent the values for the personality styles in the TEAKS agents.

The third set of variables where fuzzy values are considered is related with the project's tasks. Two of the seven task's attributes have been *fuzzified* using also three fuzzy sets. The first fuzzy set represents a *low* value in the level of *difficulty* and *specialisation* required to execute the task. The second fuzzy set represents the *medium* level and the third fuzzy set is the *high* level of difficulty and specialisation required in the task (see Figure 3.6). Similarly to the fuzzy values in the attributes of the TEAKS agents, these two task's attributes are used during the process to simulate the individual and work team behaviour.

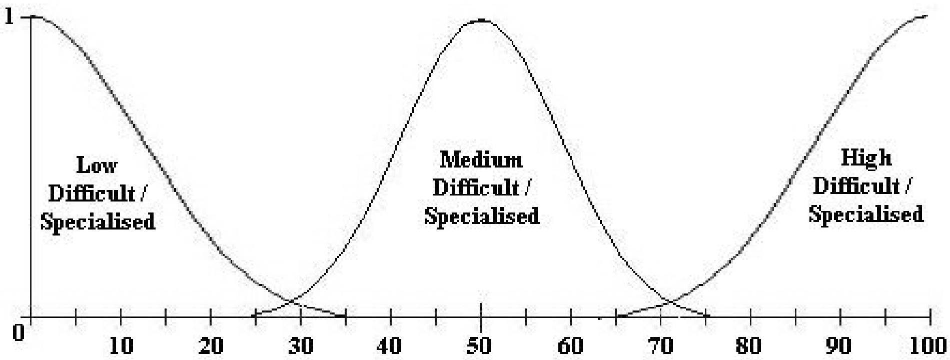

Figure 3.6. Fuzzy sets defined to represent the *difficulty* and the *specialisation* level required in the task's attributes.

3.6. Summary

This chapter has introduced and presented the general architecture of the TEAKS model, more specifically with the description of the internal model of the TEAKS agents for the representation of the real team candidates. Each agent is represented by a set of human attributes including the *cognitive-related* capabilities, a set of *basic emotions* elicited by the context of the agent (i.e. the characteristics of the assigned task(s) and the individual characteristics of the other team-members), a *personality style,* and some selected *social-related* skills. Each attribute has some specific variables such as *the role in the team,* the level of *creativity* and the level of *experience* of the team members for the *cognitive-related* capabilities. The basic emotions include the *interest* and *desire* as positive influence in the agent's behaviour, and *anxiety* and *disgust* as the negative emotions. The personality styles implemented in the TEAKS agents were selected from [Merrill and Reid, 1999] and include the *amiable, expressive, analytical* and *driver* personalities. Finally, the social-related factors included in the agent's model are the *introverted/extroverted; work alone/work with others* preferences, and the *trust* level of the agents with respect of their team mates.

This chapter also describes how a project is modelled in TEAKS. A project consists of a limited number of tasks. Each task has seven descriptive attributes including, for example, the *number of agents* assigned, the *estimated duration* of the task, the level of *difficulty* and the level of the *required specialisation* to execute the task.

A key characteristic of the TEAKS model is the use of fuzzy logic to get a *better* and *more realistic* representation of the defined human and task attributes. The last part of this chapter explains how the values of the attributes are *fuzzified* through the design of fuzzy sets with a Gaussian function using different ranges to define the degrees of membership for each value. The attributes, values and their representation in the agents and the project described in this chapter are the basis to simulate the human behaviour within a work team, a process that it is described in the next Chapter 4.

Chapter 4

TEAKS: Modelling the Team Members Interaction and the Work Team Behaviour

Society exists only as a mental concept; in the real world there are only individuals
Oscar Wilde (1854-1900).

4.1. Introduction

During the simulation design process, once the main entities of the phenomenon under study and their environment have been modelled, the next step is to define how these entities interact between them and with the environment. Thus, for the TEAKS scenario it is necessary to define how the selected attributes in the agents will direct the behaviour at the individual level and how the agents' behaviour, when interacting with the others (as part of the environment), will affect the global work team's performance. In this sense, this chapter is concentrated in the description of the algorithm and the processes (rules) that generate the agents' behaviour and govern the agents' interaction. As a first step towards this end, the following section presents the selected set of parameters used to evaluate the individual and global performance of the work team.

4.2. Evaluating the Performance

Since the ultimate goal of the TEAKS simulation is to analyse and compare the performance obtained from different work team configurations, a key component of the model is how to represent the *measurement* of the work team performance, at both, the individual and the global levels. The selection of performance metrics to evaluate individuals and the project's outcomes has been largely studied in the Project Management [Lewis, 2002] and Human

Resources Management [Bratton and Gold, 1999] fields. The aims and advantages of the execution of the *performance appraisal* process include the provision of feedback to employees that improve subsequent performance; the identification of employee training needs, the documentation of criteria used to allocate organisational rewards, the opportunity for organisational diagnosis and development, and the facilitation and enhancement of the communication between employee and administrator, among others [Patterson, 1987].

Although the correct selection of evaluation performance metrics largely depends on the type of work that will be assessed, some general indicators are currently suggested such as *quantity, quality, timeliness, cost-effectiveness, absenteeism/tardiness, adherence to policies,* among others. For the TEAKS model, five general indicators of individual performance have been selected trying to cover a wide range of project's types:

- ***Level of goals achievement.*** In the TEAKS model, when the simulation process begins, the default goal for every agent is the development of its assigned tasks until finalising them. This goal represents the commitment of each worker at the initial stage of the project. Nevertheless, this variable represents the level of accomplishment achieved for each task assigned to each agent, and it is influenced by its internal state and by the external environment (the characteristics of the task itself and the characteristics of the team mates working in the same task).

- ***Timeliness.*** It represents the level of delay or advance for each agent to accomplish its tasks taking with respect to the estimated duration attribute of the task.

- ***Achieved quality.*** Similarly to timeliness, this variable represents the level of achieved quality in the task, taking as reference the expected quality attribute of the task.

- ***Level of collaboration.*** This variable represents the collaboration level achieved by every agent with the rest of the team mates when working together. It is mainly influenced by the *trust* level achieved among the agents as it is deeply explained in the section 4.3.3.

- ***Level of required supervision.*** It represents the effort that the project manager would dedicate to a direct and frequent supervision to the agents while performing their tasks. This variable is influenced by the relation between the cognitive attributes of the agents regarding the level of *difficulty* and the *type* attributes of the task.

Two of these performance parameters are also used to evaluate the global work team performance: the *quality* and *timeliness* achieved in the all tasks during the simulated execution of the project. The values in both indicators are influenced by the values obtained at the individual level as it is explained in the section 4.3.

Similarly to the attributes in the agents and tasks, the values in each one of the five performance metrics are represented through fuzzy sets. For the *quality* and *level of collaboration* metrics, five fuzzy sets were defined representing the *low, regular, acceptable, high* and *excellent* values (see Figure 4.1). The *goals achievement* metric uses also five fuzzy sets representing the *very low, low, minimum, acceptable* and *satisfactory* values. In the *required supervision* indicator, four fuzzy sets were created to represent the *permanently, constantly, periodically* and *eventually* values. Finally, the *timeliness* metric has been defined through five fuzzy sets representing the *high delay, low delay, normal, low advance* and *high advance* values for each task once its simulated execution is performed.

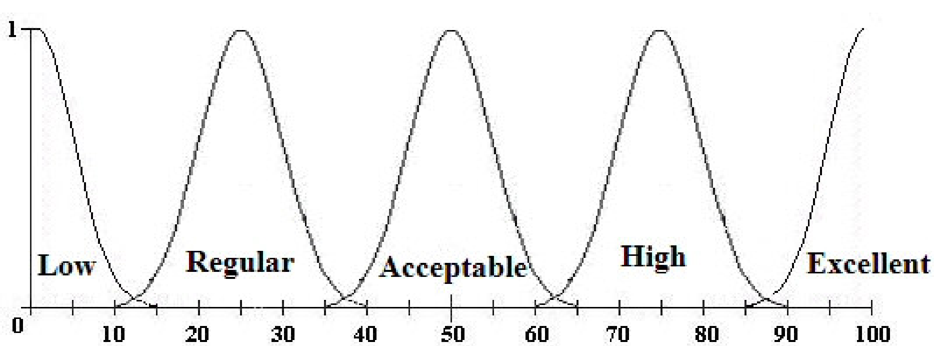

Figure 4.1. Fuzzy sets for the *quality* and *level of collaboration* metrics.

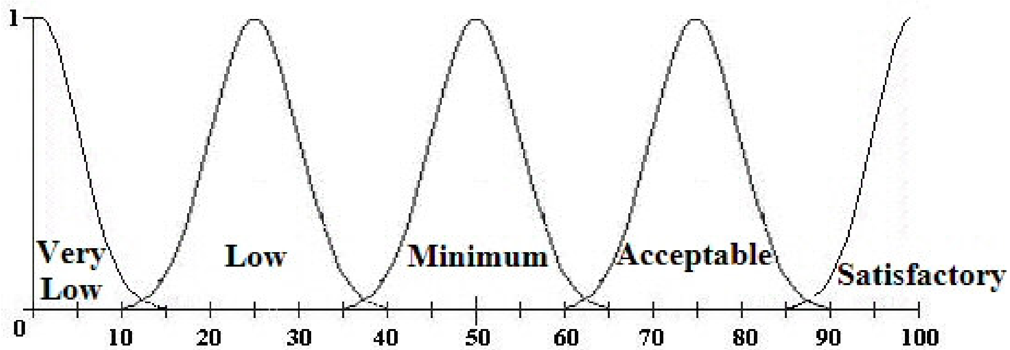

Figure 4.2. Fuzzy sets for the *goals achievement* performance metric.

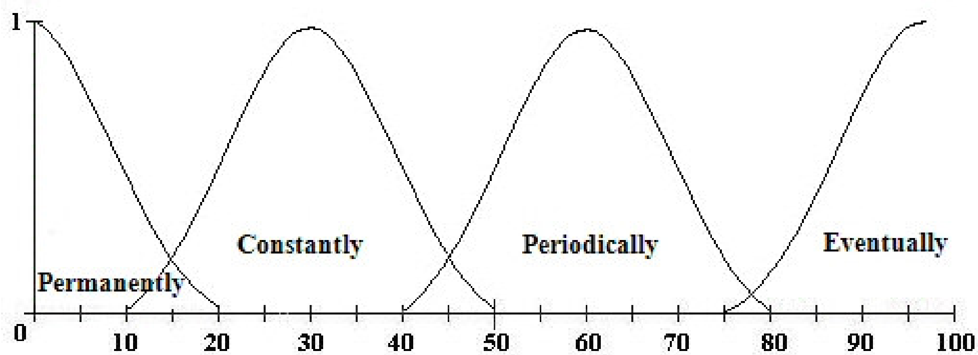

Figure 4.3. Fuzzy sets for the *required supervision* performance metric.

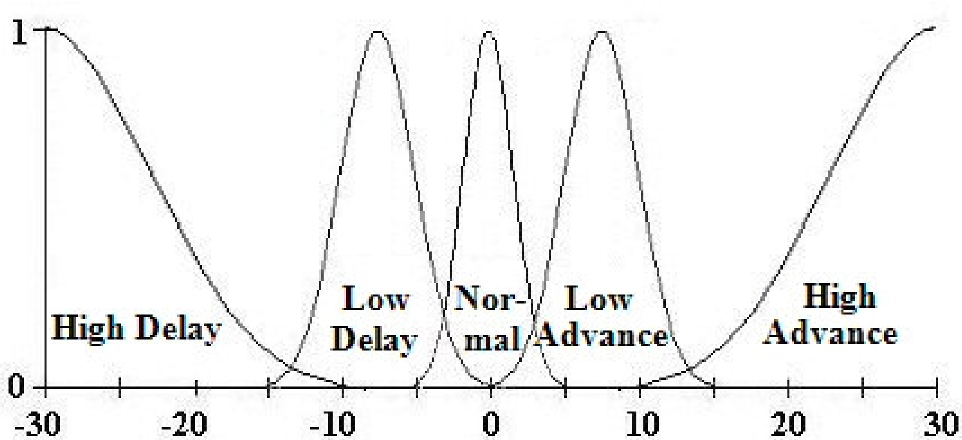

Figure 4.4. Fuzzy sets for the *timeliness* performance indicator.

After having the model of the attributes in the agents, the model of their context, and the measurement indicators of their simulated performance, the next important characteristic to represent in TEAKS is how the behaviour at the individual level is generated. The behaviour generation process at the agent level will then allow the characterisation of the global behaviour in the work team producing as an outcome the possible performance of the team. This process is explained in the following section.

4.3. Modelling the Behaviour in the Work Team

The modelling of the behaviour at the individual and team level is performed through the interaction of the agents' internal attributes with respect to the other team members and with the assigned tasks during the simulated execution of the project. This interaction, at the individual level, will direct the possible performance of each agent over its assigned tasks depending on the different values in the agent's and task's attributes at specific moments during the execution of the project. A three-step cyclical process has been developed to represent the complete interaction between agents and tasks beginning with the initial assignation of tasks to each agent until the last tasks of the simulated project finish (see Figure 4.5).

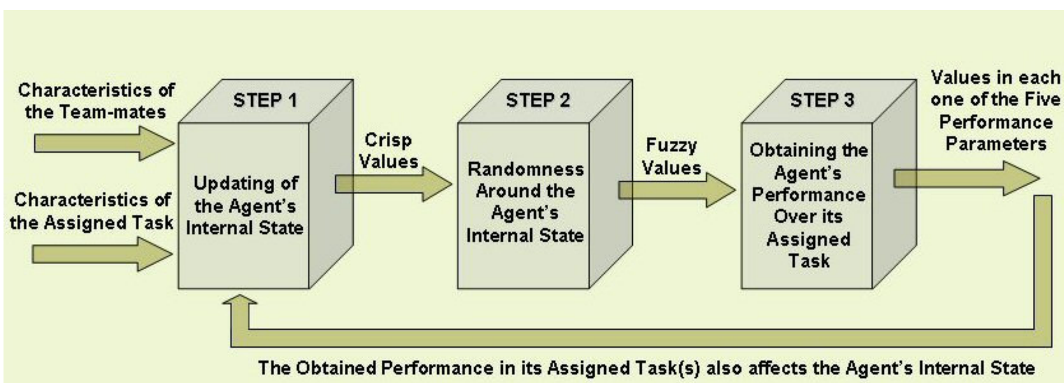

Figure 4.5. The three-step cyclical process to model the team members' behaviour.

During the execution of each step in this cyclical process, different *behaviour rules* are fired depending on the values in the attributes of the agents and tasks. These rules are, in the ultimate instance, the mechanism that produces the value in the different performance metrics of each team member over each assigned task. The complete algorithm that implements the three-step cyclical process is presented in the Figure 4.6:

1. A task t_i is assigned to an agent a_j
2. The emotional state of a_j is affected by the particular characteristics of t_i and by the individual characteristics of the other agents (if any) that also participate in t_i
3. *Trust tendency* values of a_j regarding its team mates are generated.
4. Stochastic values are generated around the emotional state of a_j representing a degree of randomness in the behaviour of the agent.
5. The value in the five performance metrics of a_j over t_i are generated influenced by the values in the internal attributes of a_j
6. The values in the emotional state of a_j and the values in the trust level regarding a_j's team mates are generated from the result obtained in the performance indicators.
7. The agent a_j receives the next subsequent task t_k (if any) to be executed (go to the step 1) until the project is finished.

Figure 4.6. General algorithm for the modelling of the team members' behaviour.

Different *behaviour rules* are executed at each step of the algorithm. It is important to note that each set of rules were defined using as source of knowledge the available (mainly organisational and psychological) literature about how the different human attributes selected for the TEAKS model influence job performance. The initial set of rules was then refined with the advice provided by an expert in Work Psychology. The detailed process and the rules involved are presented in the following sections.

4.3.1. Influencing the emotional state of the agents

When the process is started, each agent sets its emotional state (i.e. the four basic emotions) to a *medium* value of representing an *emotional equilibrium* at the beginning of the project (although in real life the emotional state of a person can be influenced by task-external factors, the TEAKS model is concentrated in the elicitation of the emotions originated from the task and team-mates attributes). This initial emotional state is altered according to the characteristics of the task that has been assigned to each agent (step 1 in the algorithm of behaviour) and also according to the personality of the other participants in the task.

The level of arousal for each emotion differs in each agent moderated by its own personality (as it is presented in the Table 3.2, each personality style has its own preferences with respect of the task and the others' personalities) and by its own cognitive capabilities (representing for example that the level of anxiety produced by a *high specialised* and *difficult* task may be different in a *high experienced* person that in a person with a *low* level of experience). All the internal and contextual attributes that influence the elicitation of the emotions are presented in the Table 4.1.

Contextual Factors: Assigned Tasks and Team-mates Attributes
Level of advance/delay of the precedent task(s) to the current assigned task.
Task difficult
Task specialisation level
Team-mates personality styles.
Internal Factors: Agent's attributes
Cognitive: Experience level and role within the team.
Social-related (introverted/extroverted, prefers to work alone/prefers to work in team).
Personality styles.

Table 4.1. Internal and contextual factors that influence the emotional state of the agents.

The arousal levels in each elicited emotion ranges from a *high decrease* to a *high increase* of the elicited emotion (see Figure 4.7). The rules involved in the changes of the emotions' intensity were defined using also fuzzy sets in the antecedent and in the consequence of the rules. For the matching rule, the Mamdani fuzzy rule-based model [Mamdani and Assilian, 1975] (the minimum operator) to represent the "AND" in the premise and the implication was used.

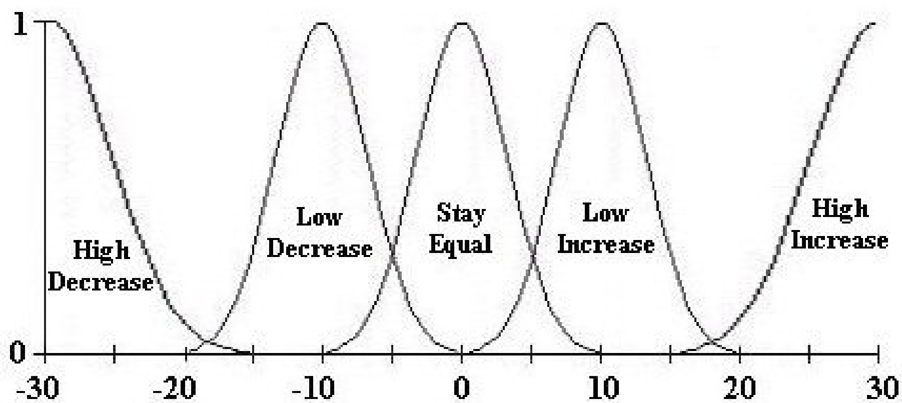

Figure 4.7. Fuzzy sets used in the rules to increase/decrease the arousal level in the emotions.

The following are examples of the rules defined to generate the values in the emotional state of the agents.

Let the task *T* assigned to the agent *A*, the emotional state of *A* is obtained through:

IF *T* is received with *high delay* AND *A* has a *highly driver* personality THEN

The *desire* of *A* to perform *T* will have a *high increase*

The *interest* of *A* to perform *T* will have a *high increase*

The *disgust* of *A* to perform *T* will *remain equal*

The *anxiety* of *A* to perform *T* will have a *low increase*

AND

IF *A* has a *high* preference to work alone AND *T* involved more agents THEN

The *desire* of *A* to perform *T* will have a *high decrease*

The *interest* of *A* to perform *T* will have a *low decrease*

The *disgust* of *A* to perform *T* will have a *high increase*

The *anxiety* of *A* to perform *T* will have a *low increase*

AND

IF *T* has a *high* level of difficulty and *A* has a *medium* level of experience in developing this type of tasks, THEN

The *desire* of *A* to perform *T* will *remain equal*

The *interest* of *A* to perform *T* will have a *low increase*

The *disgust* of *A* to perform *T* will *remain equal*

The *anxiety* of *A* to perform *T* will *remain equal*

...

All these rules defined to modify the emotional state are executed in parallel by each agent every time a new task is assigned.

4.3.2. Introducing Randomness in the Behaviour

After every agent updates its emotional state according to the executed fuzzy rules, the current values of each emotion are then defuzzified and random variations around each of the crisp value are introduced (Step 4 in the algorithm of behaviour presented in Figure 4.6). This stochastic feature is introduced trying to represent the non-deterministic *nature of human emotions*: given the same person under similar situations, his/her reaction in front of these situations will not always be exactly the same. For instance, influenced by a particular mood, in turn influenced by external circumstances, that, in our case, could lead the worker to appraise differently the same type of task interacting with the same colleagues [Stevens, 2007].

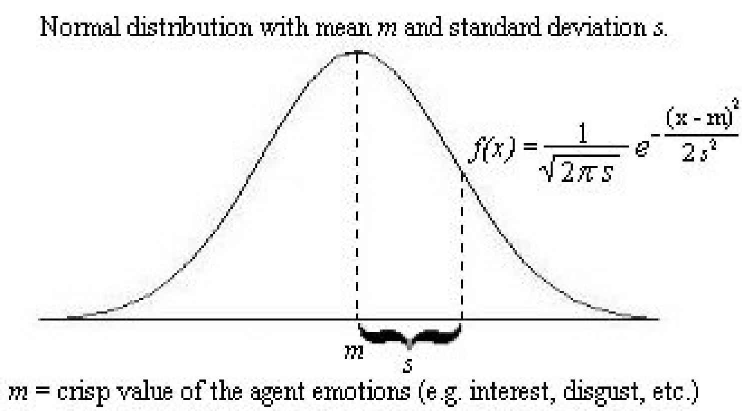

Figure 4.8. Normal distribution curve used to generate the random values around the agent's emotional state.

The randomness that is introduced at this stage of the model generates different statistical results during each executed simulation, even if the same team and project configurations are used. The random variations are obtained using a normal distribution curve (see Figure 4.8) around the defuzzified value of each emotion. Once the value in the emotion is modified from the random variations, the new value in each emotion is fuzzified again to set the new intensity of the agent internal state and continue with the next step in the algorithm.

4.3.3. Modelling the Trust Attribute

Once the four emotions are updated from the internal and contextual characteristics, the *new* emotional state of each agent is then used to update one of the social-related attributes: the trust level between the team members working on the same task. Due to the importance of trust relationships within work teams presented in section 2.3.4 of Chapter 2, a particular model of trust has been implemented in the TEAKS model. The TEAKS trust model is based in the concept of trust defined by [Vangen and Huxam, 2003], where *trusting attitudes are reinforced each time an outcome meets expectations. The outcome becomes part of the history of the relationship, increasing the chance that partners will have positive expectations about joint actions in the future and the increased trust reduces the sense of risk for these future actions.* Although this approach of trust is related to inter-organisational collaboration, this vision of trust is adopted for TEAKS in terms of trust at the individual level where the outcome results obtained in every jointly developed task influence the *trust level* between the team-mates. Therefore in the TEAKS model, the following assumption is done:

1. *Good results in the developed tasks increase trust and bad results decrease trust among the participants in the tasks.*

Additionally, since the internal state of each agent is considered as fundamental in the generation of the individual and team behaviour, the TEAKS model also includes the influence of this internal state in the trust attitudes of the agents. Specifically, the set of emotions and the personality styles of the agents modelled in TEAKS are used as additional influences on the increasing or decreasing the level trust between the team members.

Regarding the influence of emotions on trust, the findings reported by [Dunn and Schweitzer, 2005] on five studies that were developed to analyse this type of influence are used for TEAKS. In these studies the authors used six emotions as case of study: *anger*, *gratitude*, *happiness*, *pride*, *guilt* and *sadness*. One of the results they obtained suggests that happiness and gratitude, emotions with positive valence, increase trust, and anger, an emotion with negative valence, decreases trust. Nevertheless, the generalisation that all negative-valence emotions would decrease trust and that all positive-valence emotions would increase trust must not be assumed given the appraisal control of the emotions. In one of these studies four emotions were characterized by either positive or negative valence and either appraisals of other-person control (anger and gratitude) or appraisals of personal control (pride and guilt). In this study the authors found that *"emotions with appraisals of other-person control influenced trust in a manner consistent with the emotion's valence; anger decreased trust and gratitude increased trust. Emotions with personal control influenced trust significantly less than did emotions with other-person control; participants in the gratitude condition were more trusting than were participants in the pride condition, and participants in the anger condition were less trusting than were participants in the guilt condition"*.

In the TEAKS context, any of the four modelled emotions (*anxiety*, *disgust*, *interest* and *desire*) can be considered as an emotion with a personal control appraisal because each of them are caused by the context of the agent (i.e., the characteristics of the assigned tasks and the characteristics of the other team-members) and not directly by the agent's actions (although the obtained performance also influence the emotions, TEAKS does not consider emotions such as pride or guilty that can be directly influenced by the simulated actions of the agents).

Therefore, the second assumption used in the TEAKS model of trust is that:

2. *Anxiety and disgust influence negatively the trust behaviour of an agent, while interest and desire influence positively the trust behaviour of an agent.*

The other individual attribute in every agent that influences the trust level is the personality style. There are few studies about how personality traits affect interpersonal trust within work teams, and the results reported by [Lumsden and Mackay, 2006], which identify some types of personality that induce more trust than others are used in TEAKS. Although the goal of this study was to analyse the trust of people when shopping online, we use these findings to set a variable that we call ***trust tendency*** representing the tendency of a team-member to trust in its team mates when no previous interaction with them has occurred. This study considers four personality traits to analyse how trust is affected:

- *Popular Sanguine:* the extrovert, talker, and optimist. Individuals with this personality type are generally appealing to others. They are enthusiastic and expressive and live life in the present.

- *Perfect Melancholy:* The introvert, thinker and pessimist. Individuals with this personality type are generally deep, thoughtful and *analytical*.

- *Powerful Choleric:* the extrovert, doer and optimist. Individuals with this personality type are independent and self-sufficient.

- *Peaceful Phlegmatic:* the introvert, watcher and pessimist. Individuals in this category tend to be easy going and agreeable or *amiable*.

The four personality types used in this study are very similar to the four personality styles modelled in TEAKS and even some of the words are used as synonyms to describe them. Then, the following matching between the two sets of personality traits was done:

- Popular Sanguine → Expressive.

- Perfect Melancholy → Analytical.

- Powerful Choleric → Driver.

- Peaceful Phlegmatic → Amiable.

According to the results presented in [Lumsden and Mackay, 2006], *popular sanguine* personalities are optimists who focus on the details of a 'story', they were the most trusting of the respondents. The assessment of trustworthiness of *perfect melancholy* personalities was the lowest and yet they attribute the highest importance to trust triggers (i.e., the attitudes and factors that promote trust). Next to popular sanguine personalities, the optimistic *powerful choleric* personalities were the most trusting of the respondents. Finally, the pessimistic *peaceful phlegmatic* personalities got lower trustworthiness ratings and they appear to have attributed relatively high importance ratings to trust triggers.

Using these results, a third assumption was done for the modelling of trust in TEAKS:

3. *Agents with Expressive and Driver personalities have a higher tendency to trust in their team-mates that agents with Analytical and Amiable personalities*.

Similarly to the other agents' attributes, we have defined fuzzy sets to represent the values of trust, trust tendency and the values for the increment/decrement of the levels of trust in each agent during the simulation (see Figure 4.9).

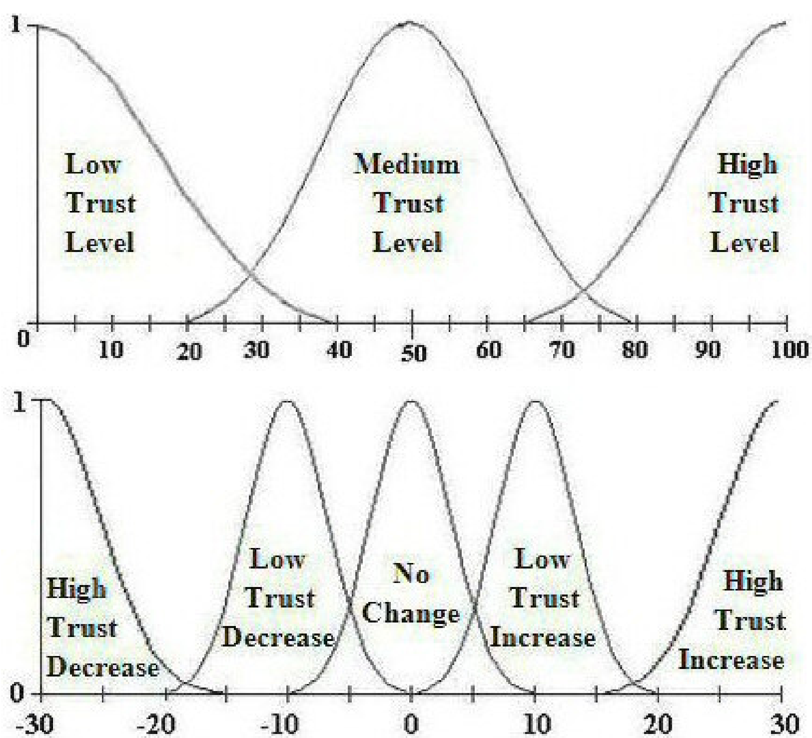

Figure 4.9. Fuzzy sets defined for the trust values (upper shape) and for the trust change values (lower shape).

Using these fuzzy sets, the process to generate the trust relationship between the different team members starts after the updating of the agents' emotional state (step 3 of the algorithm behaviour presented in Figure 4.6). Following the first assumption introduced above, the trust level is only increased/decreased depending on the performance results that are obtained in the task where the agents have interacted. Given that the update in the emotional state at step 2 in the algorithm behaviour is due to the characteristics of the tasks and not by obtained results (i.e. the task is not performed yet), the values in the trust level cannot be generated but the already introduced concept of ***trust tendency*** is used as the tendency of an agent to trust its team-mates. The values in the trust tendency variable in each agent are obtained as follows:

- If there is no previous interaction between the team-mates, then the value of the trust tendency of each agent concerned to its team-mates is obtained from the current internal state (the value in each one of the emotions) and from the personality of the agent. The values in trust tendency are also fuzzy values obtained from fuzzy sets similar to those used for the trust parameter (Figure 4.9).

- If there is a previous interaction between the agent and its team-mates (i.e., the agent has already participated in a previous task with the other agent) then the trust tendency value is only influenced by the current emotional state of the agent. This represents that the tendency to trust in a person is affected by the personality style only when the agents have not *met each other* previously, but once they have interacted, the trust is only affected by the emotions and the results in the tasks.

The fuzzy rules used to get the values in the *trust tendency* are based on the assumptions 2 and 3 previously presented. Examples of these rules are the following.

Let two agents A_i and A_j interacting on the same task:

IF the *desire* emotion of A_i has a *high* intensity THEN

The *trust tendency* of A_i regarding A_j will have a *high increase*

AND

IF the *anxiety* emotion of A_i has a *medium* intensity THEN

The *trust tendency* of A_i regarding A_j will have a *low decrease*

AND

IF A_i has a *high expressive* personality style THEN

The *trust tendency* of A_i regarding A_j will have a *high increase*

...

It is important to note that in the TEAKS model, there is no historical information about previous interaction of the agents in former projects, i.e., at the beginning of each new simulation the trust level is set to *medium* level in all the agents and the values in the trust tendency are obtained from the agents' emotional state and personality styles. A graphical representation of the complete model of trust implemented in TEAKS is presented in the Figure 4.10.

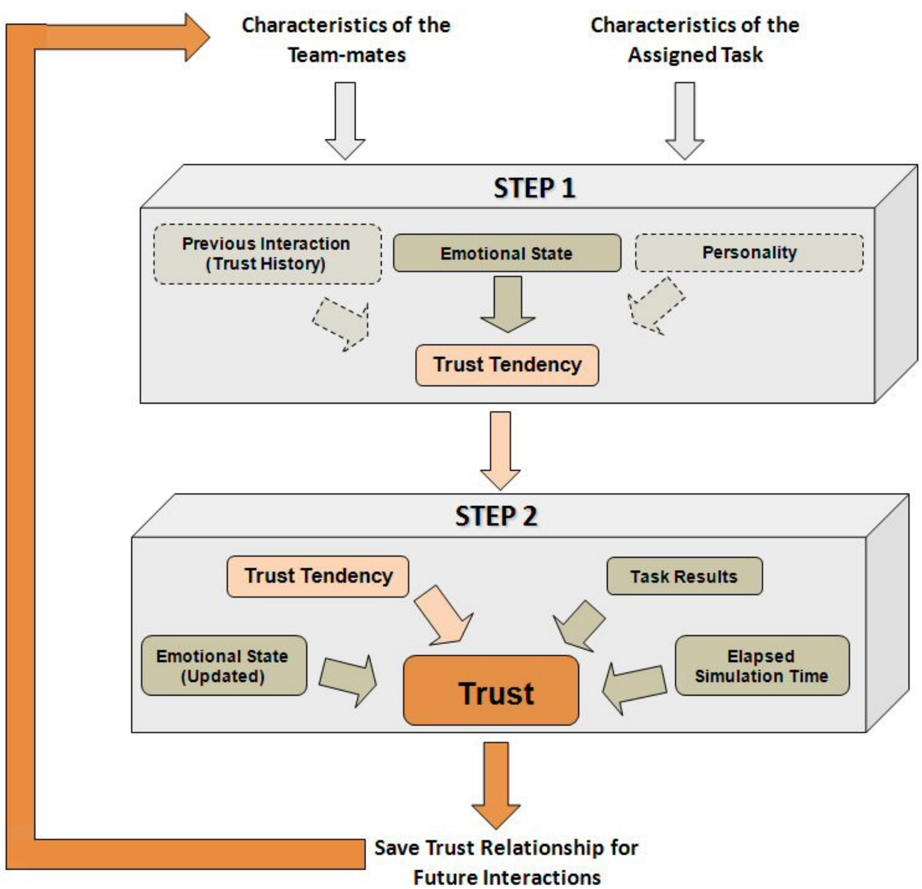

Figure 4.10. The model of trust in TEAKS.

Once the task is executed, the values in the agents' performance are generated and at this moment the trust level between the participants in the finished task is obtained (see the "Step 2" box of the trust model presented in the above Figure 4.10). The process to get the agent individual performance is explained in the following section.

4.3.4. Getting the Performance Values

After getting the values in the emotional state and in the trust tendency variable of each agent and after the introduction of the stochastic process around each emotion, the values of each one of the five performance indicators are obtained (step 1 in the algorithm of behaviour presented in the Figure 4.6). Similarly to the process to modify the emotional state and the trust tendency attributes, the values in the performance metrics are obtained from the execution of a set of fuzzy rules where the premises are some of the internal and contextual attributes of the agents. The increment or decrement in the performance values are also defined through the implementation of five fuzzy sets representing values from *high decrease* to *high increase* for each performance indicator (see Figure 4.11).

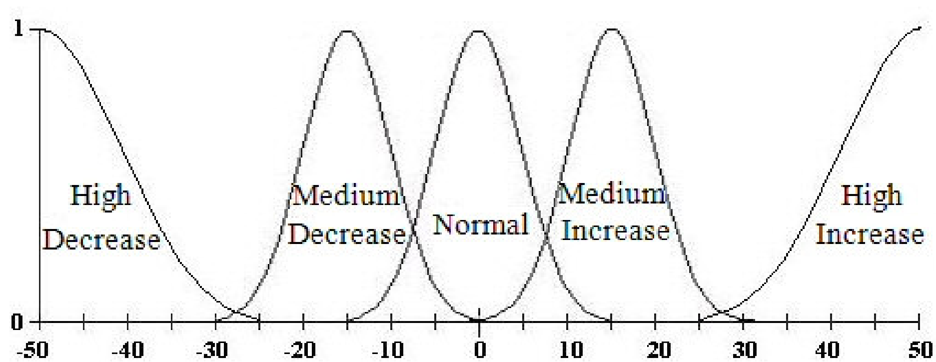

Figure 4.11. Fuzzy sets used to increase/decrease the value of the five performance metrics.

The fuzzy rules defined to get the values in the performance metrics have been based on several studies that present how the different modelled attributes in TEAKS influence the performance at work of an individual. These studies include the analysis over the performance originated by the level of *experience* [Dokko et al., 2009], [Quiñones et al., 1995], [Avolio et al., 1990], by the *creativity* attribute [Scott et al., 2004], [Feneuille, 1997], by emotional states

[Kelly and Spoor, 2007], [Jordan et al., 2006], [Isen, 2000], by the trust between the individuals [Costa, 2003], [Jones and George, 1998], and by the particular characteristics of the personal styles.

In concrete, the attributes used as premises in the rules to obtain the values for the five performance indicators are presented in the Table 4.2.

Contextual Factors: Task Characteristics
Task difficult
Task specialisation level
Internal Factors: Agent's attributes
Cognitive: level of experience and level of creativity.
Emotional state (the four modelled basic emotions).
Social-related factor: the trust level.
Personality styles.

Table 4.2. Internal and contextual factors used to get the values in the performance indicators.

Examples of the rules to obtain the values of the performance indicators are the following.

Let the agent A_i working on the task T_j:

IF A_i has a *high* level of *experience* in tasks similar to T_j THEN

The *timeliness* of A_i over T_j will have a *medium advance*

The *quality* of A_i over T_j will have a *high increase*

The *goals achievement* of A_i over T will have a *medium increase*

The *team collaboration* level of A_i in T will have *medium increase*

The *required supervision* level of A_i in T will have a *medium decrease*

AND

IF A_i has a *high* level of *disgust* THEN

The *timeliness* of A_i over T_j will have a *high delay*

The *quality* of A_i over T_j will have a *high decrease*

The *goals achievement* of A_i over T_j will have a *medium decrease*

The *team collaboration* level of A_i in T_j will have *high decrease*

The *required supervision* level of A_i in T_j will have a *medium increase*

AND

IF A_i has a high level of *creativity* AND T_j requires a *high specialisation* level THEN

The *timeliness* of A_i over T_j will have a *medium advance*

The *quality* of A_i over T_j will have a *medium increase*

The level of *goals achievement* of A_i over T_j will be *normal*

The *team collaboration* level of A_i in T_j will be *normal*

The *required supervision* level of A_i in T_j will be *normal*

AND

...

With regard to the effect of *trust* over the performance of the team members, there are also some fuzzy rules to increase/decrease three of the performance indicators in the team members: *timeliness, quality* and *level of collaboration*. The *level of required supervision* and *the level of goals achievement* metrics are not strongly influenced by the *trust* level between the team members (a purely social skill attribute) and these three variables have been excluded from the rules where the trust level acts as the premise. Examples of these rules are the following:

IF the *trust level* of A_i regarding its team mates on T_j is *high* THEN

The *timeliness* of A_i in T_j will have a *medium advance*

The *quality* of A_i in T_j will have a *medium increase*

The *team collaboration* level of A_i in T_j will have *high increase*

AND

IF the *trust level* of A_i regarding its team mates on T_j is *low* THEN

The *timeliness* of A_i in T_j will have a *high delay*

The *quality* of A_i in T_j will have a *high decrease*

The *team collaboration* level of A_i in T_j will have *high decrease*

...

After the execution of all the rules that meet the values in the premises, the performance metrics for each agent over the corresponding task is obtained. Additionally, two of the performance metrics of the team members are also used to evaluate the global work team performance: the resultant task *timeliness* and task *quality*. The global values of these parameters are obtained as follows:

- ***Task timeliness*:** it is obtained from the minimum timeliness value selected from the set of agents assigned to the task. It represents that although some agents could finish their part of the task in advance (i.e., the assigned agent takes less time to do the task than the task's *estimated duration*), if any agent finishes its part of the task with some delay then the final *timeliness* of the task will be this obtained delay.

- ***Task quality*:** the final quality of the task is obtained through the arithmetical average of all the (crisp) quality values of the agents involved in the execution of the task.

4.3.5. Updating the Emotional State and the Trust Relationship from the Achieved Performance

Once the performance of each agent is obtained from the simulation of the execution of a task, the values of five performance indicators are used to update the emotional state and the trust level of every team member (step 6 of the algorithm behaviour described in the Figure 4.6). The update of the emotional state represents the effect that the obtained task results have over the emotions in all participants in the task: positive values in the task performance will influence the positive and negative emotions of the agent moderated by its own personality style. The modelling of this feature assumes that a person knows his/her performance once his/her assigned task is finished. Although in real life it is not common that evaluation results are known immediately after the every task is finished (it is most common get the evaluations until the end of the project), there could be some indirect indicators that may allow the person to make an internal appraisal about his/her obtained performance.

The second agent's attribute to update at this stage is the level of trust towards the team mates that participate in the same finished task. Depending on the results (*quality* and *timeliness*) obtained in the task, the value in the trust level is acquired using the following inputs (refer to the box labelled as "step 2" in the

Figure 4.10):

- *The current emotional state* that in turn was updated according to the values obtained in the performance indicators.
- *The trust tendency* that was previously set when the task was assigned to the agent.
- *The task results*.
- *The elapsed simulation time*: the simulated time from the start until the end of the project is used to represent different variations in the trust level. Constant variations in the trust level are more frequent at the beginning than at the end of the project when the trust relationship is normally established (e.g. when a good/bad relationship of trust between two agents has been built during the first and medium stages of the project, it is more difficult that this level of trust decreases/increases at final stages of the project, unless something really bad/good occurs).

After this step, the trust level of the agent regarding each one of its team mates in the task is stored as the *trust history* to be used in future interactions, i.e. when the two agents will jointly interact in a subsequent task of the project. It is important to mention that the initial trust value of all the team members is set to *medium,* which represents the not trust and not distrust of an agent regarding its team mates. This is based on most psychological approaches that state that trust starts at a zero baseline and gradually develops over time [Jones and George, 1998], as evidence of trustees' qualities and relationship history increases.

Examples of the rules defined for the updating of the emotional and trust attributes in the agents are the following.

Let the task T_j assigned to the agent A_i and interacting with the agents $A_x \dots A_z$:

IF A_i has a *high degree* of *driver* personality AND the obtained *quality* in T_j was *high* THEN

The *desire* of A_i will have a *low increase*

The *interest* of A_i will have a *low increase*

The *disgust* of A_i will *remain equal*

The *anxiety* of A_i will have a *remain equal*

AND

IF A_i has a *high degree* of *amiable personality* AND the obtained *timeliness* over T_j was a *high delay* THEN

The *desire* of A_i will have a *low decrease*

The *interest* of A_i will *remain equal*

The *disgust* of A_i will have a *low increase*

The *anxiety* of A_i will have a *high increase*

AND

IF the *trust tendency* level of A_i regarding A_x is *low* THEN

The *trust* level of A_i regarding A_x will have *low decrease*

IF the obtained *quality* of A_i over T is *excellent* THEN

The *trust* level of A_i regarding A_x ... A_z will have a *high increase*

...

After updating the emotional state and the trust level, each agent can be assigned with a new task (step 7 of the algorithm behaviour described in the Figure 4.6), starting again with the process explained in the section 4.3.1. All these steps of the behaviour algorithm are repeated each time a team member receives a new task until all the tasks of the project are completed.

4.4. Summary

This chapter has explained the model implemented in TEAKS to evaluate the individual and work team performance. In concrete, five performance metrics are used to evaluate the individual performance: the *level of goals achievement,* the *timeliness* and *quality* achieved in the assigned tasks, the *level of collaboration* of every team member with respect to its team mates, and the level of *required supervision*. Additionally, two of these metrics are also used to evaluate the global performance of the work team: the final *timeliness* and *quality* achieved in all the tasks of the project. The model of each performance indicator is, as the model of the agents and tasks internal attributes, also based on fuzzy logic where different fuzzy sets have been defined to represent a different range of values in the performance metrics.

The model of interaction and behaviour between the team members has been also addressed in this chapter 4. The general algorithm defined to generate the behaviour and performance of each agent through the simulated execution of the project has been presented and the specific steps have been detailed. The behaviour algorithm involves a set of fuzzy rules that are executed to modify some of the internal attributes in each agent which in turn influence the final achieved performance. Specifically, the agent's attributes that are modified during the simulated execution of the project are the emotional state and the trust level with respect of the other team members. Both types of attributes are changed through the execution of the fuzzy rules which use as premises the contextual (task and other team members' characteristics) and other agent internal values. The specific model of trust is detailed and the trust evolution between the team members is mainly based on the *good* or *bad* results obtained by the agents in their assigned tasks.

The complete TEAKS model presented in chapter 3 and chapter 4 has been implemented into a software simulation tool, which will allow project managers to analyse different work team configurations. The architecture of this software simulation tool is presented in the following chapter 5.

Chapter 5

Implementing TEAKS: From an Agent-Based Model to a Software Simulation Tool

It is by acts and not by ideas that people live
Anatole France (1844-1924).

5.1. Introduction

After a model has been designed representing the specific phenomenon under study, the next important step is to transform this model into a working system that allows the later validation of the proposed model [Gilbert and Troitzsch, 2005]. The implementation of TEAKS as a software simulation tool has this main objective: the validation of the proposed model and ideally its further use in real life by the project managers. Following this objective, the implementation of the TEAKS model has been developed and the main characteristics of the software design are presented in this chapter. The chapter starts describing a set of requirements in the simulation tool that have been used to select the software libraries for the development of the software. The software multi-agent architecture is also presented in this chapter through the identification of the complete set of agents implemented in the simulation software. The main functionalities of the simulation tool and the validation of the implementation are also described in this chapter.

5.2. Software Libraries Used

The implementation of the TEAKS model into a working and easy-to-use simulation tool involved the study and selection of the existent programming frameworks that facilitate the model implementation. There are currently several tools that help the development process and avoid a complete implementation of a model from scratch. According to the particularities of the model and to the desired characteristics of the final tool, a set of existent libraries were selected. Some basic requirements to fulfil were listed in order to decide which packages of programming libraries could be more adequate to use. The list of requirements includes the following:

- ***To provide a multi-agent framework.*** Since the TEAKS model is an agent-based model, the first requirement was to find a software framework capable to facilitate the development of a multi-agent environment where the number of agents and their internal characteristics can be created and modified at run-time allowing to the final users the easy creation and modification of different team configurations. The agent framework should also include a mechanism of communication between the agents to simulate the interaction between them included in the TEAKS model.

- ***To provide a reasoning mechanism based on fuzzy logic.*** As it is described in the Chapter 3 and Chapter 4, the formal roots of the model are based on fuzzy logic and most of the agents' attributes are represented through fuzzy sets. Moreover, the generation of the agents' behaviour is provided by the execution of the individual fuzzy rules, which at the end, represent the reasoning mechanism that directs the agent behaviour and produce the final performance. In this sense, it is necessary a framework that provides the functionality to define the fuzzy sets, the fuzzy rules and their mechanism to evaluate and execute these rules. Additionally this framework should also facilitate the defuzzification and fuzzification of the fuzzy values allowing the implementation of the stochastic process explained in the section 4.3.2 of the Chapter 4.

- ***To facilitate the development of a suitable GUI.*** The target users for the simulation tool are mainly project managers. This type of users do not necessary have deep computing knowledge and all programming details of the TEAKS model should be transparent for them when using the tool. The users should be able to easily configure different work teams, different projects, quickly assign and re-assign the tasks to the members of the configured team, execute the simulations, and get the results to make the analysis about the different work teams' performance results.

- Finally, the users should be able ***to save every work team and project*** configuration as well as the obtained results for a subsequent use.

Following these main requirements, a brief evaluation of existent frameworks was done, and three (free access) libraries were selected:

- ***The Java Agent Development Framework[4] – JADE***, developed by Telecom Italia is a software Framework fully implemented in the Java language. It simplifies the implementation of multi-agent systems through a middleware that complies with the FIPA[5] specifications and provides a set of graphical tools that supports the debugging and deployment phases.

- ***The JESS Rule Engine[6]*** and scripting environment written entirely in the Java language developed at Sandia National Laboratories in Livermore, Canada. This rule engine implements a reasoning mechanism over knowledge supplied in the form of declarative rules.

- ***The FuzzyJ Toolkit[7],*** a set of Java classes developed at National Research Council of Canada that provides the capability for handling fuzzy concepts and reasoning in a Java setting. This toolkit is jointly used with the JESS rule engine as the reasoning mechanism that uses fuzzy concepts in the TEAKS agents.

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[4] http://jade.tilab.com/
[5] http://www.fipa.org/
[6] http://www.jessrules.com/
[7] https://www.nrc-cnrc.gc.ca/eng/secure/php/iit_license/info/6

An additional advantage of these libraries is the fact that the three are written entirely in Java which is a multi-platform programming language. In addition, Java Swing components were used to design the GUI of the simulation tool. Moreover, the three selected frameworks offer good documentation, guides and examples of use, and there is a great community of users that support the constant improvement of these libraries, which in turn, facilitate their use and minimise the learning curve of beginners. All the three frameworks were integrated in the open source Eclipse Java IDE[8].

Having selected the background frameworks, the design of the multi-agent architecture was defined and it is presented in the following section.

5.3. Multi-Agent Architecture

During the implementation of the TEAKS model two types of agents were defined: the *team member agents* and the *system agents*. The team member agents are those agents used to represent the real candidates that make up the work team by implementing the attributes and behaviour described in the Chapter 3 and Chapter 4. The system agents are used to execute the actions related to the simulation operation. The system agents are the following:

- ***The GUI Agent.*** The Graphical User Interface Agent facilitates the interaction between the simulation software and the user. Through the GUI Agent, the user can configure the characteristics of the initial work team and the characteristics of the tasks in a simulated project. The GUI Agent also allows the user to assign tasks to the corresponding team member agents, and the analysis of the simulation results by showing different graphics of the generated work team performance.

- ***The Simulator Agent.*** The Simulator Agent has the control over each simulation. It manages that the number of simulations, defined by the user, are executed.

[8] http://www.eclipse.org/

- ***The Assigner Agent.*** The Assigner Agent distributes the tasks to each agent at run time according to the task assignment that has been previously done by the user. This agent also controls the tasks sequence execution according to the configuration of the project provided by the user.

- ***The Results Agent.*** This agent receives the performance results of each team member agent and performs the evaluation of the whole work team (using the *timeliness* and *quality* values obtained in all the tasks as described in the previous section) during each simulation. Finally, the Results Agent sends the individual and work team performance results to the GUI Agent for its graphical visualisation.

Both types of agents are created from the main JADE *Agent* class, with their corresponding attributes, methods and behaviours (see the class diagrams of the system and team member agents in the Appendix A. Class diagrams of the TEAKS Agents). This agent architecture allows the user, through the GUI Agent, to select an initial work team by configuring the real people's characteristics in the team member agents and configure the tasks of the project. When the simulations start, the Simulator Agent takes the control of the total number of simulations and during each simulation the Assigner Agent informs to each team member agent which task have to perform. Once each team member agent simulates the execution of the task and gets its performance, the result of each team member is informed to the Results Agent. This information is shown to the user through the GUI Agent and can be saved for further references. The configuration of each work team analysed and its corresponding project can be also saved. The complete multi-agent architecture is graphically shown in Figure 5.1.

In order to effectively implement in the simulation tool the complete functionality described above, all the agents (both the *team member* and *system* agents) need to exchange some pieces of information between them. So, it has been necessary to implement a basic communication protocol to support the execution of the simulations with the information provided by the user.

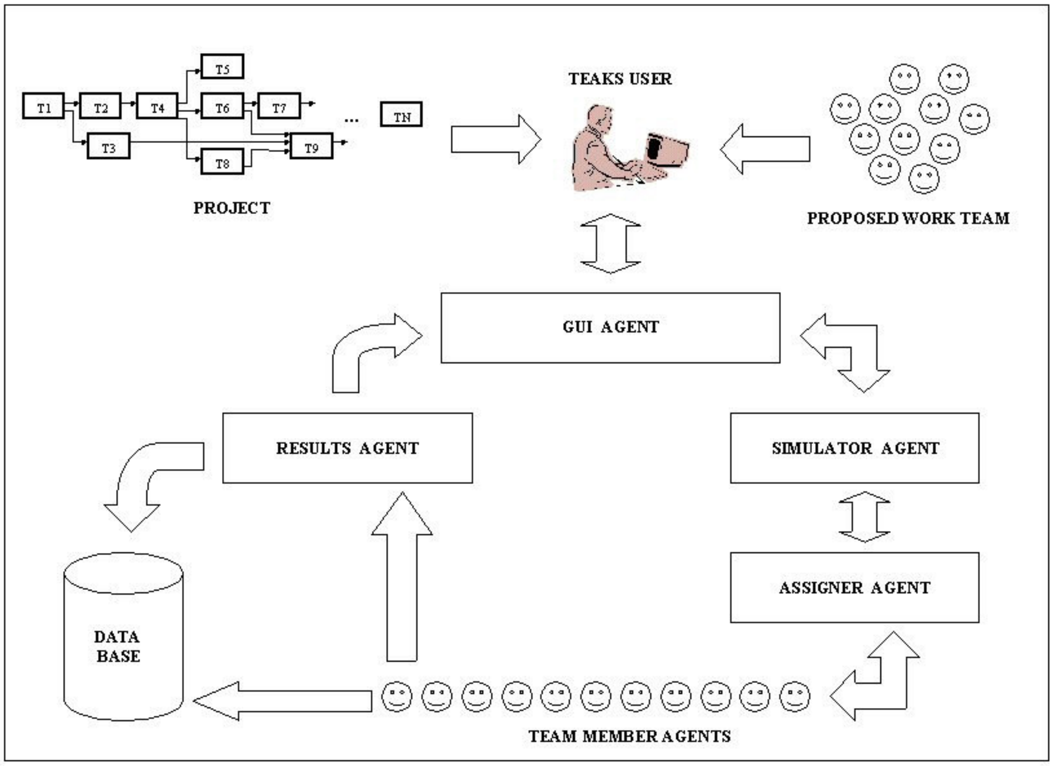


Figure 5.1. Multi-Agent Architecture.

5.3.1. The Agents Communication

The basic communication messages implemented in the TEAKS simulation tool are based in the Agent Communication Language (ACL) standard of FIPA. As already mentioned in the section 5.2, the JADE framework is FIPA-compliant and provides the complete infrastructure to implement the FIPA communication protocols.

In summary, the communication between TEAKS agents starts when the user starts the execution of the simulations. At this moment, the GUI Agent sends a *request* message to the Simulator Agent containing in the message the number of simulations required by the user. Then, the Simulator Agent *requests* in turn to the Assigner Agent the assignment of the tasks according to the configuration defined by the user. After receiving this request, the Assigner Agent identifies the first tasks of the project to be executed and searches (through the Directory Facilitator provided by JADE) the agents that have been assigned to these tasks.

The Assigner Agent *requests* the execution of the tasks sending the ID of the tasks to every team member agent assigned to the tasks.

At this stage, the team member agents reproduce the behaviour explained in Chapter 4 and the individual performance results are generated (one example of how the rules that produces the team members' behaviour are implemented with the JESS engine is presented in the Appendix C). These results are then sent from each team member agent to the Results Agent, which will collect all the results and will calculate the work team global performance through the method explained at the end of the section 4.3.4 of Chapter 4. All these communication messages are exchanged until the Assigned Agent identifies that all the tasks in the project have been executed and informs to the Simulator Agent the completion of the project. The Simulator Agent then verifies if the total number of required simulations have been performed. If not, the Simulator Agent requests to the Assigner Agent the new assignment of the tasks. If yes, the Simulator Agent informs to the GUI Agent that all the requested simulations have been executed. Once the GUI Agent receives this message, it requests the complete set of results to the Results Agent. The results are then sent from the Results Agent to the GUI Agent, which graphically displays them to the user. The complete TEAKS agents' communication is presented in the diagram of Figure 5.2.

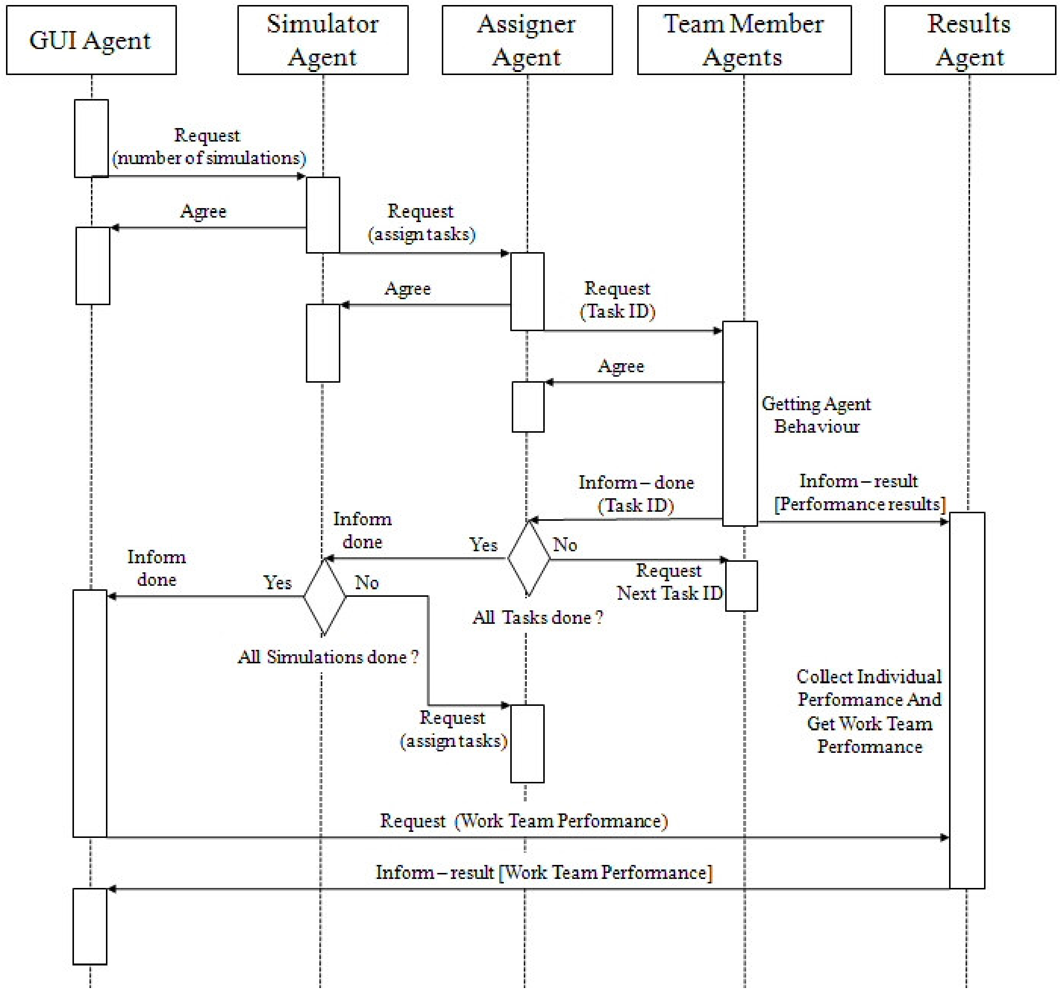


Figure 5.2. Diagram of communication between the TEAKS agents.

5.4. The TEAKS Simulation Prototype

In terms of functionality, the TEAKS software simulation tool has been developed with three main components: the configuration, the simulation and the results spaces. A brief summary of the main functionalities provided by each space is presented in the following sections.

5.4.1. The TEAKS Configuration Space

The first step that the users of the TEAKS simulation software have to perform is the configuration of the initial work team and the configuration of the project. As already mentioned in the section 3.2, the work team can be configured using the real characteristics of the team candidates as well as the configuration of the tasks taking the real information from the project to be developed.

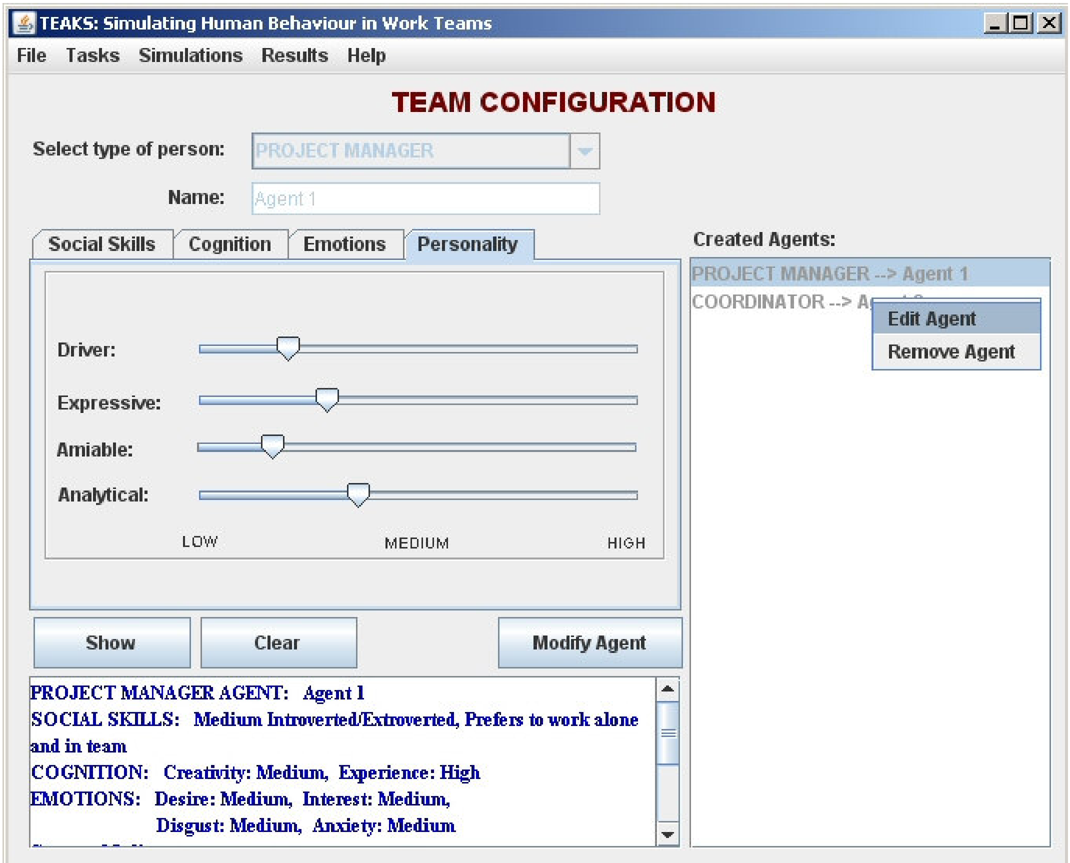


Figure 5.3. Team configuration window.

In the Team Configuration window (see Figure 5.3) the user sets all the required information of each team member starting with its role in the work team, and then following with the setting of the values of all the agent's internal attributes. Through this main window, the user can create all the necessary agents to form the work team, edit their characteristics, save the complete work team and load past configurations.

Other configuration window is shown in Figure 5.4, where the user can create the representation of the tasks in the project and setting the values in the task's attributes. The software provides a graphical tool where each task is represented with a rectangle and the lines between the rectangles represent the task dependencies. Similarly to the creation of the work team, this window allows the users to edit, to save and load the project's tasks.

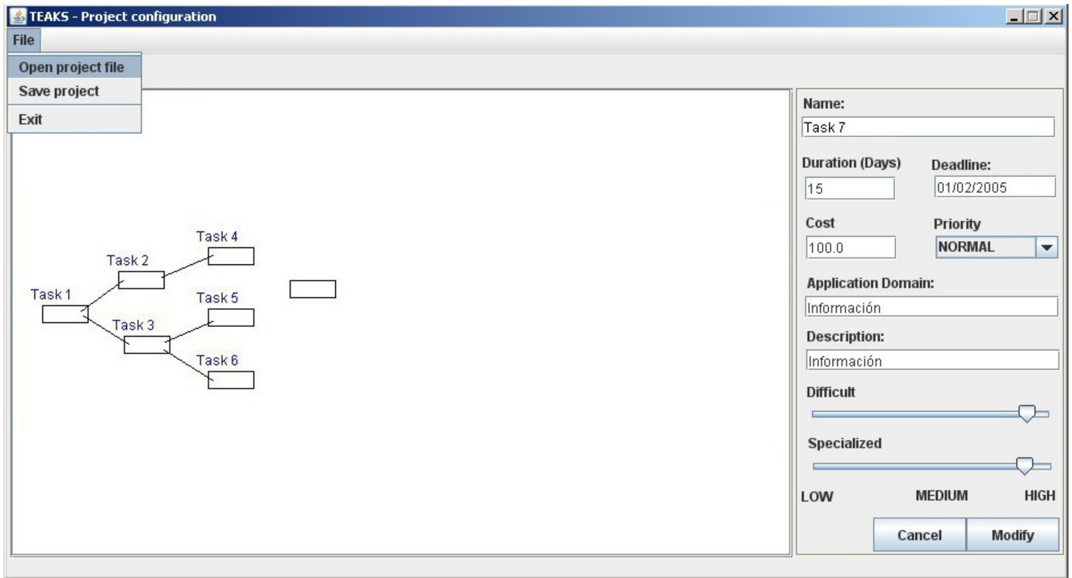


Figure 5.4. Project configuration window.

Once the work team and the project have been created, the next step is the assignment of the tasks to each team member. The task assignment can be done by the user through the assignment window presented in the Figure 5.5. At run time, when the simulations are executed, the information produced by this assignment process is used by the Assigner Agent to distribute the tasks to the corresponding team member agents.

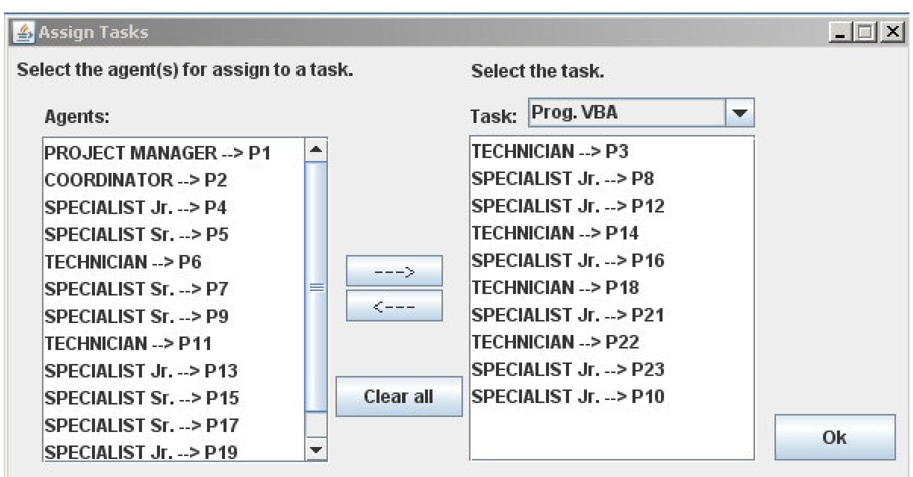


Figure 5.5. Tasks assignment window.

5.4.2. The TEAKS Simulation Space

Once the work team and the project have been configured, the simulations can be started. At this step the user has the option to define some settings before the execution of the simulations. The first parameter to set is the value of the standard deviation (around the defuzzified emotion's values) used during the introduction of the randomness in the agents' behaviour process (see section 4.3.2 in Chapter 4). The default value of this parameter is set to 10. After the execution of some tests, we have derived that the suitable range of values in this parameter would be from 10 to 20: the use of smaller values produce small variations in the emotions of the agents producing almost always the same results in the performance independently of the number of executed simulations (invalidating the purpose of the introduction of randomness in the model). On contrary, greater values in this parameter produce big differences in the performance results across the different numbers of simulations making difficult the identification of behaviour and performance patterns.

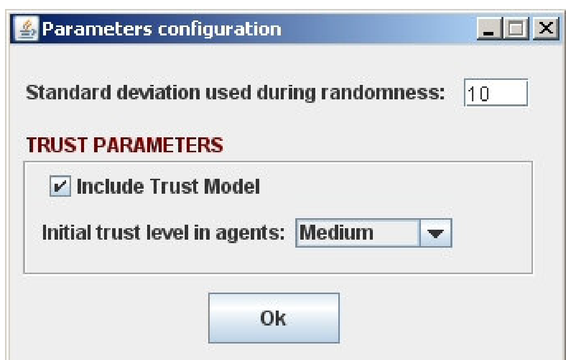


Figure 5.6. Simulation settings window.

The second parameter to set gives the option to the user whether to include the trust model explained in the section 4.3.3. If the trust model is included, then there is also the option to define the initial value in the agents' trust level used at the beginning of the project: *low*, *medium* or *high*. The default value of this parameter is set to *medium*. Although this parameter can be modified by the users, this option was included mainly to analyse, in the context of this research, the effect of *trust* in the individual and in the work team performance (this analysis is presented and discussed in the next Chapter 6). Thus, when the TEAKS simulation software is used by project managers, the current default values in these parameters should be maintained.

The final requirement to start the simulations is to set the number of simulations to be run. After that, all the process that generates the behaviour and the interaction in the agents, through the execution of the complete set of fuzzy rules, is executed and the statistical information about the possible work team performance is produced.

5.4.3. The TEAKS Results Space

After the complete number of simulations is executed, the results module of the TEAKS simulation tool provides a set of graphs containing the statistical information about the possible individual and work team performance. These graphical results facilitate an easy interpretation and analysis of the data generated by the simulations. Different graphics are presented showing the resultant *timeliness* and *quality* of each task in the project as the global work team performance. Additional graphics are provided to show the statistics about the individual performance obtained by all the team members over every assigned task where the values in each one of the five performance indicators can be analysed. All the performance graphics can be also saved for further reference.

The Results space also provides a meta-analysis (useful in terms of research but might not for project managers) of the simulated behaviour of the agents by showing all the fuzzy rules that were executed throughout the simulations. During the implementation of the TEAKS simulation software, this meta-analysis was mainly used to verify the correct execution of the behaviour rules according to the values taken in the premises. This meta-analysis also provides information about the trust evolution between the team members throughout the completion of the project.

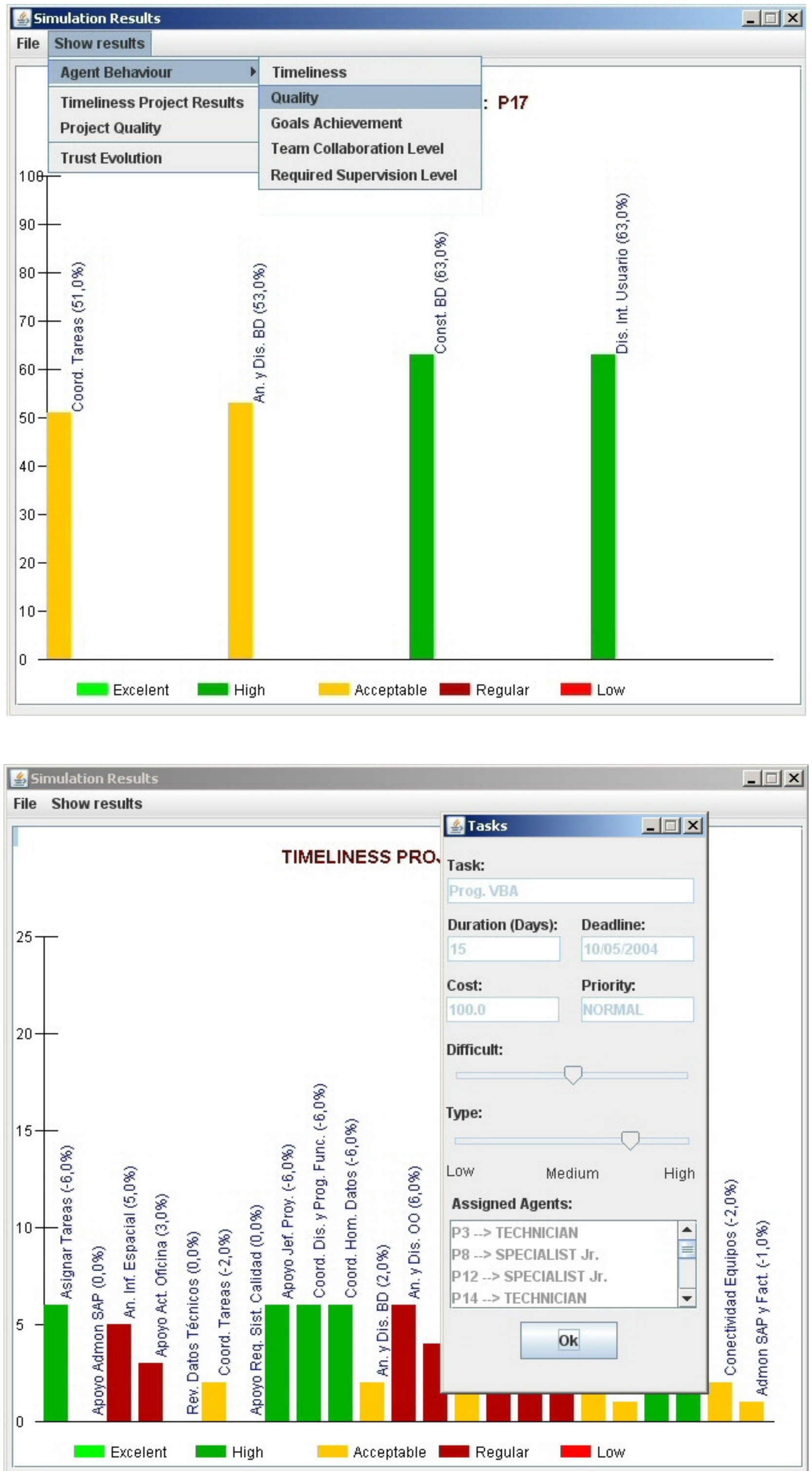


Figure 5.7. Results window.

5.5. Implementation Validation

As introduced in Chapter 1, a model is usually developed for the study/analysis/understanding of a real complex phenomenon. In order to evaluate if the implementation of the model correctly implements the theories and assumptions underlying the conceptual model, it is necessary to do some experimentation tasks to define the applicability of such model [Sargent, 2007]. One experimentation approach is the *implementation validation* of the simulation software that would allow the identification of possible programming errors, but it must be done mainly to assure that the computational system correctly implements the conceptual model.

The process of implementation validation performed in the TEAKS simulation tool mainly allowed to test that the behaviour produced in the agents was according to the fuzzy rules based on the conceptual model and defined at each step of the behaviour algorithm. The validation step was done through the setting of a work team and project using empirical data (i.e. the characteristics of both, the work team and project were not taken from a real scenario). The work team was configured including 10 team members (1 project manager, 1 coordinator, 3 specialists, 3 technicians and 2 assistants) assigned to a project with 12 tasks. The values in each agent's attributes were arbitrarily assigned as well as the values in the *difficulty* and *required specialisation* level of the tasks. In the simulation settings, the standard deviation was set to 10 and the initial trust level in the agents was set to *medium*.

After the execution of 50 simulations, the interpretation of the statistical information shown in the graphics of performance got to the following conclusions:

- The most delayed tasks were those that have been assigned to agents with *medium* to *high* values in the *anxiety* and *disgust* attributes, jointly combined with high values in the *amiable* or *expressive* personality style. The delay in these tasks was independent from the values in the *difficulty* and *required specialisation* levels of the task.

- The tasks with the higher quality were those performed by agents with high values in the *creativity* attribute and *medium* to *high* values in the *interest* and *desire* attributes.

- The tasks with the lower values of quality were performed by agents with high or medium values in the anxiety emotion faced with a highly difficult task. Nevertheless, the quality of a task is less affected by this type of agents than the task timeliness.

- High values in both, the quality and timeliness indicators, were obtained in *high specialised* tasks assigned to agents with high levels of *analytical* personality style combined with a high level of experience.

- The level of *trust* in the agents was lesser increased towards those team mates that interacted in tasks that got medium to low quality values than towards those team mates that interacted in tasks with *high* values obtained in the quality performance indicator.

After executing the first 50 simulations, some modifications to the initial work team configuration were done. The values in the internal attributes (mainly the creativity, the level of experience, and the personality styles) of some agents were raised or lowered, representing the substitution of the agents by some others with the new values. Additional modifications were done in the assignment of the tasks by removing or replacing some agents to some selected tasks. New simulations were executed after the introduction of each set of modifications to observe the effect in the work team performance. Some of the observed results include the following:

- When an agent is replaced by other agent with similar characteristics (similar values in the cognitive and personality attributes), the *quality* and *timeliness* in the task(s) where the replacement takes place were quiet similar.

- When agents with bad performance caused by the negative emotions were replaced by agents with higher experience or a higher role in the work team (specialist or coordinator), the performance (in all the five metrics) was better than in the replaced agent, even with similar values in the negative emotions.

- When one agent with low experience and low values in its positive emotions (*desire* and *interest*) is removed from a task, if the remaining agents over that task have medium to high level of experience and medium to high values in their positive emotions, the final achieved timeliness in the task is improved.

- Good results in a task highly influence the positive evolution of trust between the participants: better results higher the increment in the trust values, and positive trust relationship can be obtained even when the trust tendency between them (before perform the task) had negative values.

- In a task, when team members are replaced by agents with higher level of creativity, the quality of the task is improved only if the task has a high specialised level.

- When an agent is working alone in a task but its personality style is highly *amiable* and has a *high preference to work with others,* the task timeliness is more (negatively) affected than the task quality.

- The tasks assigned to agents with high analytical or driver personality combined with high level of experience and medium to high level of creativity got the best quality and timeliness. These good results are little decreased when new agents with opposite personalities and low to medium level of experience are added to the same tasks.

All these results, although expected a priori, were useful to analyse what of the pre-defined behaviour rules were executed and how these executions were generating the behaviour and final performance in each agent and in the work team. The validation of the implementation contributes to a better tuning in the premises of these rules to implement what theory explains about how the performance of a person is influenced by the different attributes. This process was also useful to evaluate the threshold in the number of simulations from which the values in the performance metrics become stable (i.e. the number of simulations from which the values of the *quality* and *timeliness* performance metrics are not drastically improved/deteriorated). Minimum or no changes in the task's performance were obtained from the simulation number 40.

5.6. Summary

This chapter has described the implementation of the TEAKS model into a software simulation tool. The initial design requirements and the software libraries used to develop the simulation tool were explained in the first part of the chapter. Then the TEAKS multi-agent architecture was presented by describing the *system agents* and communication protocols between them and with respect to the *team member* agents. The main functionalities of the TEAKS simulation prototype were also described in this chapter. These functionalities are divided into three main spaces where the users can: *i)* create and configure the work team and the project; *ii)* execute the simulations and; *iii)* analyse the obtained results. The last part of this chapter presents the implementation validation of the TEAKS simulation tool where fictitious work team and project were created. The validation process allows a good analysis of the results obtained from the behaviour algorithm and rules implemented in TEAKS.

Chapter 6

TEAKS Validation

All life is an experiment. The more experiments you make the better
Ralph Waldo Emerson (1803-1882).

6.1. Introduction

One of the most important steps in the development of a simulation model is the validation process. The Model validation can be defined as the *substantiation that a computarised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model* [Schelesinger et al., 1979]. Because that the main aim of any simulation model is the analysis and understanding of a specific phenomenon that contributes to solve problems and to aid in decision-making, the users of these simulation tools are rightly concerned with whether the model and its results are *correct* [Sargent, 2007]. Quite often it is too costly and time consuming to ascertain that a model is *completely* valid over a specific domain. Instead, some tests and evaluations are conducted until sufficient confidence is obtained to say that the *model is considered valid for its intended application* [Sargent, 1984].

The validation of the TEAKS model was precisely done through the execution of tests and evaluations within the domain by using information of a real work team in a large company. In concrete, the TEAKS model validation process was developed following two of the fifteen validation techniques for simulation models described by [Sargent, 2007]: the *face validity* and the *historical data validation*. Both techniques were used in the same case study at the Mexican Petroleum Institute (IMP)[9] a Mexican research and technological development

[9] www.imp.mx

centre where I had the opportunity to spend 4 months during a research stay specifically in The Research Group of Applied Mathematics and Computing.

At the IMP, as well as in other organisations, the suitable formation and configuration of a work team is essential in the success of large and complex projects. Given the interdisciplinary nature of the institution, the research and development projects at the IMP require professionals with different backgrounds including petroleum, chemical, computing engineers, psychologists, sociologists and economists, among others. People can be involved in different projects ranging from exploration, extraction and production of petroleum; design and development of specialised software systems; to management and training among others. The IMP develops projects in which only few people are required (3 to 15) and projects in which many team members need to work together (from 10 to 100 or even more) from different locations.

For the purposes of the TEAKS validation, we have worked with a medium project (developed by 23 participants) and used a (recently finished) Information Technology project. This project was selected mainly due to the availability of the project manager (to make the *face validity* process) and the accessibility to the documents used to evaluate the real performance of all the team-members involved in the project (we used some of these forms to perform the *historical data validation*). In particular, the project consisted on the design, development and implementation of a Geographical Information System (GIS) for internal use at IMP. The first part of the validation process was to identify and adapt the available information of the real work team and project in terms of the TEAKS model. After that, a set of simulations was performed in the TEAKS simulation tool and the obtained results were *i)* compared with the real evaluation of the work team and *ii)* evaluated by the project manager that was in charge of the project.

6.2. Defining the Input Values

A key advantage found in the IMP to perform the validation task was that most of the projects in the Company are very well documented from their conception until the final evaluation. Using this information and the advice of the project manager, we were able to identify the required input to the TEAKS system in terms of the team members' attributes and project's characteristics. The following two sections present in detail the values used as the input of the TEAKS simulation tool.

6.2.1. Team Members Attributes

The values in the personality and social skills attributes for each team member were obtained (using a signed permission of the project's participants) from the "Personal Proficiency Profile - PPP" Software[10] used at the Human Resources Department of the IMP. The PPP software uses four psychological traits to examine styles of behaviour at work known as DISC: ***D**ominance, **I**nfluence, **S**teadiness* and ***C**onscientious*. According to the descriptions of these behaviour styles, they were matched with the four TEAKS personality trends as following:

- *Dominance → Driver*
- *Influence → Expressive*
- *Steadiness → Amiable*
- *Conscientious → Analytical.*

The values in the cognitive capabilities (experience and creativity) were set according to the information in the curriculum vitae of each team member and complemented with the information provided by the project manager. The values in all the emotions were set to *medium* as well as in the value of trust (representing *no trust* and *no distrust* between the team members at the beginning of the project).

The complete values in all the attributes of the 23 team members (replacing the real name of each team member by *Agent x* to maintain them anonymously) are presented in the following Table 6.1:

[10] http://www.imageninstitucional.com/software%20ppp.htm

Person	Role	At1	At2	At3	At4	At5	At6	At7	At8
Agent 1	Project Manager	HE	HT	H	H	H	MH	H	MH
Agent 2	Coordinator	M	HT	H	H	H	M	MH	MH
Agent 3	Technician	M	M	ML	M	L	L	L	L
Agent 4	Specialist	M	M	ML	M	L	L	M	MH
Agent 5	Specialist	M	M	MH	H	M	L	M	M
Agent 6	Technician	HE	HT	L	M	L	ML	L	L
Agent 7	Specialist	HI	HA	MH	H	ML	M	M	M
Agent 8	Specialist	M	M	M	H	L	M	M	M
Agent 9	Specialist	HE	HT	H	H	ML	H	H	H
Agent 10	Specialist	M	M	M	M	L	M	M	M
Agent 11	Technician	M	HA	M	H	L	L	M	M
Agent 12	Specialist	HE	HT	M	M	L	ML	M	M
Agent 13	Specialist	HI	M	H	MH	MH	H	H	H
Agent 14	Technician	HE	HT	H	H	MH	H	H	H
Agent 15	Specialist	M	M	MH	H	M	M	M	MH
Agent 16	Specialist	M	M	M	M	L	L	M	L
Agent 17	Specialist	HI	M	MH	H	M	M	MH	MH
Agent 18	Technician	HE	M	ML	ML	L	L	ML	M
Agent 19	Specialist	M	M	M	M	M	M	M	M
Agent 20	Specialist	M	HA	M	ML	M	L	M	M
Agent 21	Specialist	M	M	ML	MH	M	M	MH	M
Agent 22	Technician	M	HT	M	ML	L	M	H	M
Agent 23	Specialist	HE	HT	H	MH	M	M	H	MH

Attribute	Value
At1: Introverted/Extroverted **At2:** Prefers to work alone/in a team **At3:** Creativity **At4:** Experience **At5:** Driver **At6:** Expressive **At7:** Amiable **At8:** Analytical	**HE:** High extroverted **HI:** High introverted **HT:** Highly prefers to work in a team **HA:** Highly prefers to work alone **H:** High **M:** Medium **L:** Low **MH:** Medium high **ML:** Medium low

Table 6.1. Configuration of the work team used as case study in TEAKS.

6.2.2. *Characteristics of the Project*

Regarding the characteristics of the project, 23 tasks were identified from the White Book of the project and the (TEAKS-related) characteristics were also identified from the White Book complemented with the information provided by the project manager. After having identified the project's tasks each of them was assigned to the TEAKS agents equally as the real tasks were assigned to the team members. The data of the project and the assignment of the 23 tasks are shown in the following Table 6.2:

Task	Type	Difficulty	Assigned to:
Task management. *(Asignar tareas)*	H	H	Agent 1
Analysis of spatial information. *(Análisis de información espacial)*	H	H	Agent 4
SAP Administrative support. *(Apoyo en la administración SAP)*	L	L	Agent 19
Support in administrative issues. *(Apoyo en actividades de oficina)*	L	L	Agent 6
Review of technical data. *(Revisión de datos técnicos)*	ML	ML	Agent 20
Coordination of tasks. *(Coordinación de Tareas)*	H	H	Agent 14 Agent 17 Agent 21
Support for the Quality Assurance Plan Requirements. *(Apoyo en la integración de los requerimientos del Sistema Institucional de Calidad)*	M	M	Agent 11
Project manager supportive tasks. *(Apoyo a la jefatura de proyectos)*	L	L	Agent 11
Coordination of the design and programming of functions. *(Coordinación en el diseño y programación de funciones)*	ML	ML	Agent 2
Coordination of data standards. *(Coordinación en la homologación de datos)*	M	M	Agent 2
Object oriented analysis and design. *(Análisis y diseño orientado a objetos)*	H	H	Agent 3 Agent 5 Agent 10 Agent 12 Agent 13 Agent 14 Agent 16 Agent 21 Agent 22 Agent 23
Databases analysis and design. *(Análisis y diseño de bases de datos)*	H	H	Agent 7 Agent 9 Agent 17

Programming task. *(Programación en VBA)*	MH	M	Agent 3 Agent 8 Agent 10 Agent 12 Agent 14 Agent 16 Agent 18 Agent 21 Agent 22 Agent 23
Design of SQL queries. *(Diseño de consultas en SQL)*	MH	MH	Agent 14 Agent 21
Design of GUI's. *(Diseño de interfaces de usuario)*	M	ML	Agent 3 Agent 10 Agent 12 Agent 16 Agent 17 Agent 22 Agent 23
Construction of spatial elements. *Construcción de elementos espaciales*	H	M	Agent 4
Programming of SQL queries (1). (*Programación de consultas SQL)*	ML	ML	Agent 8 Agent 18
Design and programming of SQL queries (2). *(Diseño y programación de consultas SQL)*	M	M	Agent 3 Agent 10 Agent 12 Agent 16 Agent 22 Agent 23
Database implementation. *(Construcción de bases de datos)*	M	M	Agent 7 Agent 9 Agent 17
Database validation. *(Coordinación en la adecuación de bases de datos)*	M	M	Agent 2
Spatial elements validation. *(Coordinación en la creación de elementos espaciales)*	M	ML	Agent 2
Software connectivity. *(Conectividad entre equipos)*	M	M	Agent 7 Agent 9
SAP and invoices management. *(Administración del SAP y facturación del proyecto)*	M	M	Agent 15
Values			
H: High **MH:** Medium High **M:** Medium **ML:** Medium Low **L:** Low			

Table 6.2. Configuration of the tasks (the real name of the task –in Spanish– is shown in italic font).

Using these input data and standard deviation set to 10 for the random values, 40 simulations were executed. The obtained results are presented and discussed in the following sections.

6.3. Results

The statistical results over the team members' performance generated by the TEAKS system after 40 simulations were compared with the evaluation forms used at the IMP that are filled by the project managers each time a project finishes (see the evaluation form used at IMP in the Appendix B. Performance Evaluation Form Used at IMP). These evaluation forms include a Likert scale based questionnaire over six different performance indicators which five of them are the performance metrics used in the TEAKS model. Although these evaluation forms were very useful to compare the results between the real and the TEAKS work teams regarding the values in the five performance metrics, the first main difficulty in the validation process appeared: the information about an individual's job performance is very sensitive and it was only accessed after a signed authorisation by each individual team member. From the 23 involved people in the project, only 14 authorised the access to their evaluation forms (representing the 60% of the sample).

The comparison between the TEAKS and real work team result was only possible in these 14 team members. The following graphs present the comparison between the performance results in the TEAKS system and the 14 available performance evaluation records for each performance indicator.

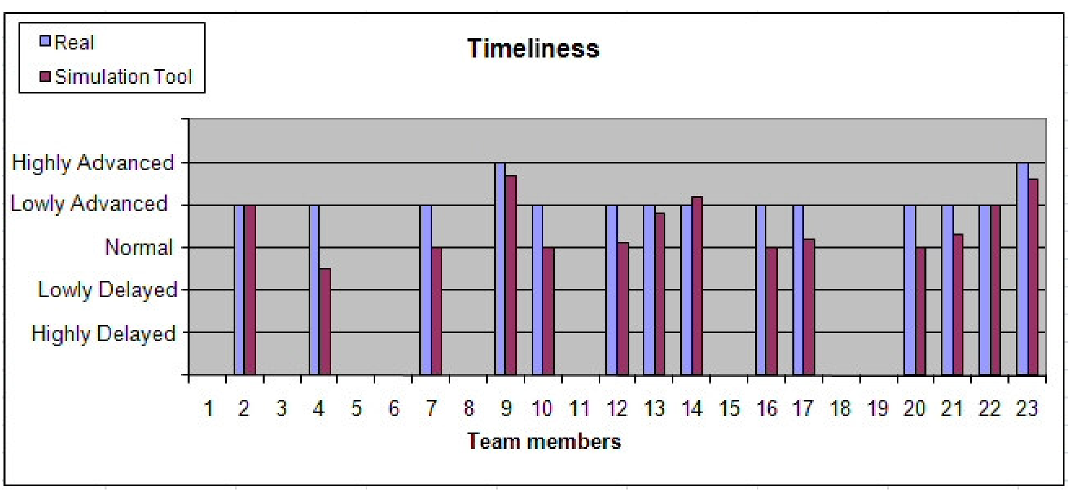


Figure 6.1. Comparison between TEAKS and real work team performance: the timeliness indicator.

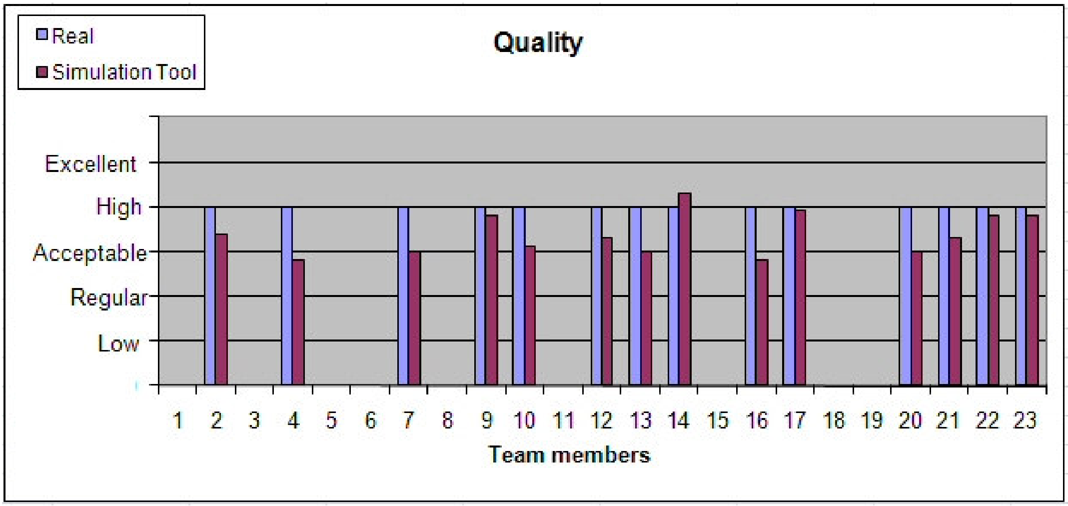


Figure 6.2. Comparison between TEAKS and real work team performance: the quality indicator.

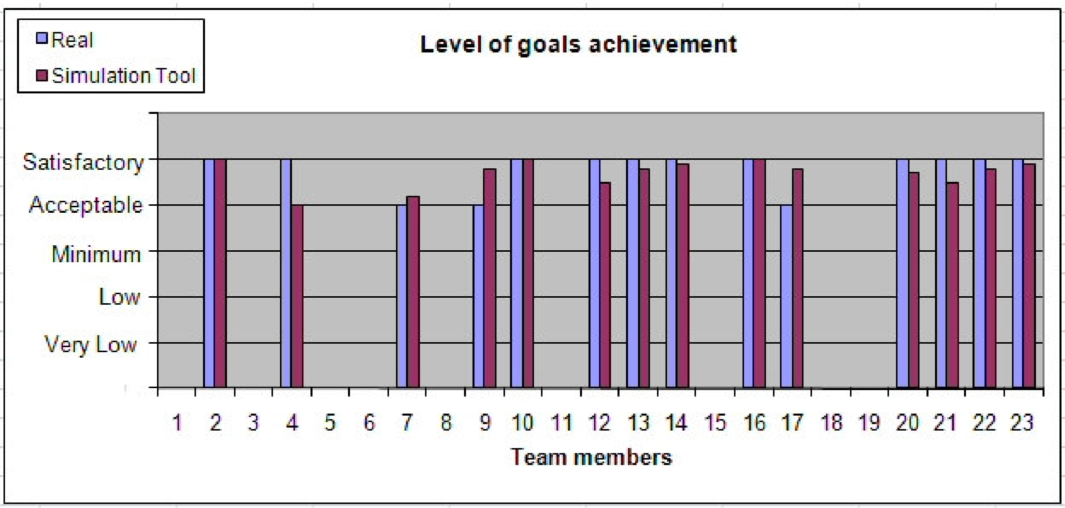


Figure 6.3. Comparison between TEAKS and real work team performance: the level of goals achievement indicator.

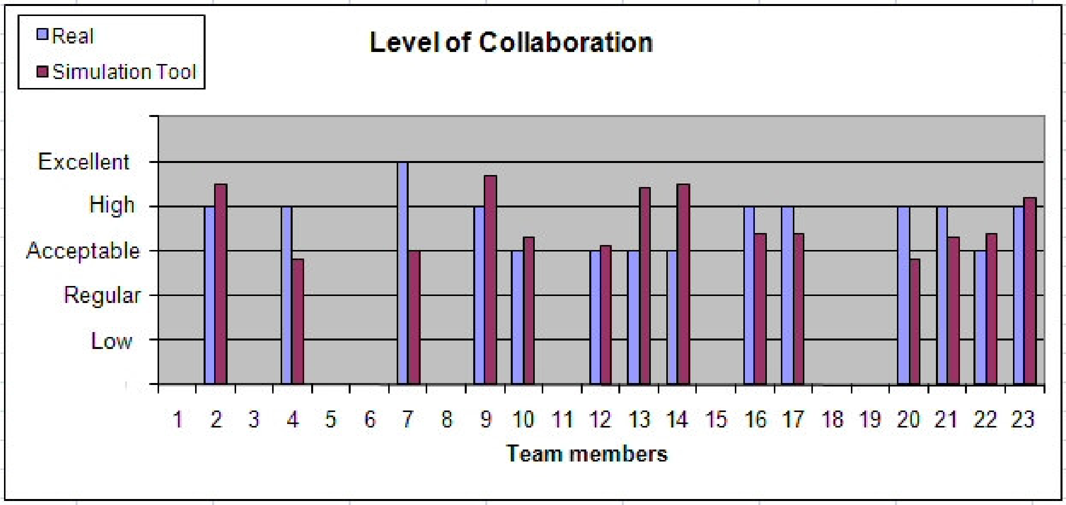


Figure 6.4. Comparison between TEAKS and real work team performance: the level of collaboration indicator.

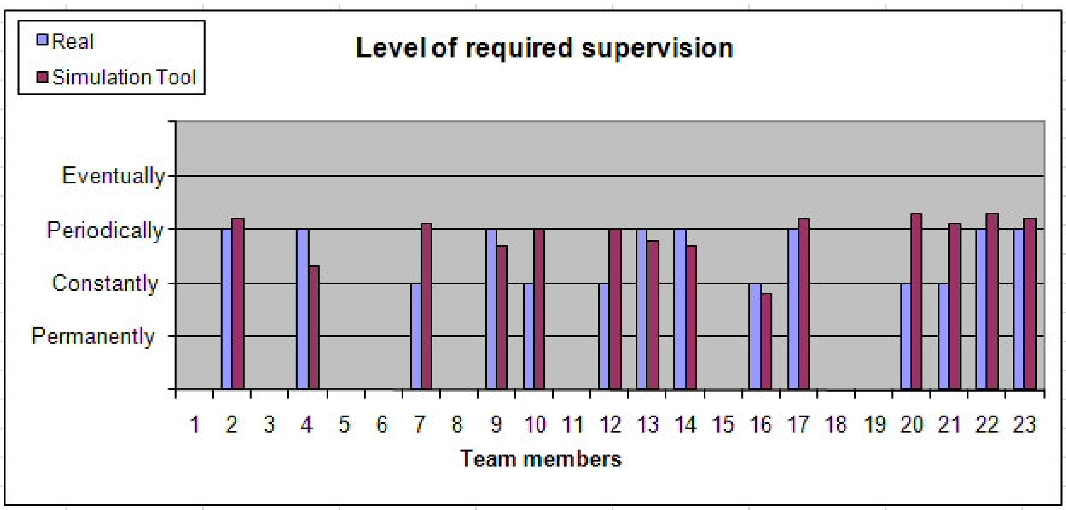


Figure 6.5. Comparison between TEAKS and real work team performance: the level of required supervision indicator.

The five graphs presented above indicate that one of the closest values between the real results and the results obtained from TEAKS was the *level of goals achievement* performance indicator where the evaluation of the project manager over the real team members ranged from *acceptable* to *satisfactory*. The obtained values from the TEAKS work team in this performance indicator was also within this interval and in 10 of the 14 team members the difference was very small[11] representing a similarity in the 70% of the available data. Similarly, in the *level of required supervision* metric, the small differences between the real and simulation results (with values ranging from a *permanently* to *eventually* required supervision) were obtained in 8 of the 14 team members representing almost the 60% of similarity.

The differences in the other three performance variables were greater representing a 43% of similarity in the *timeliness* and *quality*, and 50% in the *level of collaboration*. The higher differences were obtained in team member numbers 4, 7, 12, 13 and 16. Analysing the individual characteristics of these agents, we can see that team members 4, 12 and 16 have a range of values from *low* to *medium* in their cognitive variables, and according to the TEAKS rules, these *low/medium* values could affect their performance resulting in a *worst* simulated performance than the real reported performance. The values in the cognitive variables were higher in the other two team members (7 and 13), but they present high preferences of *introversion* and to *work alone*, an opposite requirement of the tasks where they were involved having to interact with other participants.

In terms of global work team performance, the results from TEAKS (using the method explained in the section 4.3.4 of Chapter 4) are presented in Figure 6.6, showing the global values in the *timeliness* and *quality* performance variables for each of the 23 tasks. The comparison of these TEAKS values and real data was not possible because there were no available data about the global timeliness and quality of each task in the project. For a global evaluation of developed projects at the IMP, other different parameters are used such as the *client satisfaction* or the evaluation of differences between the estimated and real consumed *budget* during the whole life of the project. Thus, the validation of the global work team performance was performed using the *face validity* technique asking to the project manager about the suitability of the results. The

[11] Note that small differences were due to the fact that the simulation's results presented in the graphs represent the defuzzified (crisp) values in each performance variable allowing intermediate values around the fixed values reported in the IMP's evaluation forms.

evaluation of the generated results and the general comments about the TEAKS software made by the project manager were satisfactory and positives.

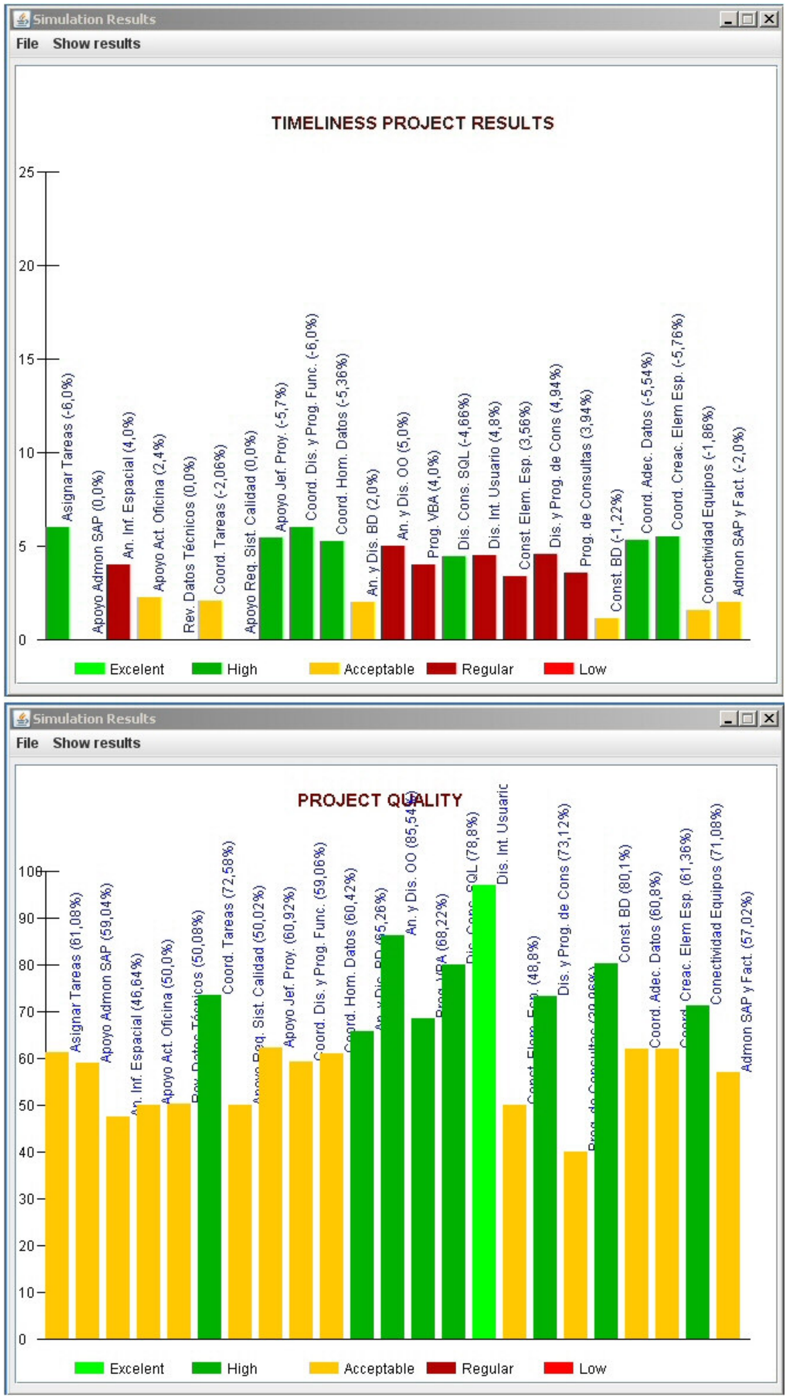


Figure 6.6. Work team global performance obtained from TEAKS: the *timeliness* and *quality* values for the 23 tasks of the project.

In words of the project manager, "*given the input values used in TEAKS and the configuration of the rules, the results are interesting and resemble a part of the reality*". The project manager considered that TEAKS would be a useful tool for novel project managers in charge of their first work team formation, or even for experienced project managers but facing the configuration of a work team with candidates who had never interacted before in past projects.

From the results, we can observe that the *timeliness* and *quality* of tasks in charge of only one team member depended directly on the internal values of the team member: the values in their cognitive capabilities and their emotional state influenced the final values in the *timeliness* and *quality* of the task in a similar way as it was previously explained in the comparison of the simulated and real data at individual level.

In those tasks with a high number of participants (n > 3) presented a *regular* value in the timeliness parameters (representing some degree of delay regarding the estimated ending date) but the *quality* obtained in these same tasks ranged from *acceptable* to *high*. Finally, tasks with small number of participants (1 < n <= 3) presented *better* results in the *timeliness* value ranging from *acceptable* to *high* (representing that these tasks were finished on time or even with a little advance with respect to the estimated ending date) and the obtained *quality* in these tasks was *acceptable*. An interesting analysis over those tasks assigned to more than one team member is to know how much the *trust* between the team members influenced the results, which is done in the next section.

6.4. Analysing the Effect and Evolution of Trust

As it was introduced in the Chapter 1, one of the main advantages of simulations is the feasibility to *play* with the parameters and values in the simulation's model to analyse the effect that these changes have on the global behaviour of the system. In this sense, the TEAKS simulation software can be used to analyse the influence of the different individual attributes over the work team performance. In concrete, the analysis of the evolution in the trust level attribute was performed to study how it affects the individual and global performance of the work team. The selection of this parameter was mainly done by the fact that it is a dynamic parameter that it is constantly modified by the results that are obtained in the tasks, while it is moderated by the emotions and the personality styles. In this sense, the changes in the values of this attribute can be studied throughout all the simulation process. On the contrary, the values in the cognitive, personality and the other social-related factors are set from the beginning of the simulations and remain constant during all the steps of the simulated project (the introduction of some kind of *dynamic* behaviour in some of these attributes is something that it can be done in further research, as it is explained in the last Chapter 7).

At the individual level, we executed again 40 simulations but at this time excluding the trust model at the settings of the simulation. The Figure 6.7 presents the comparison between the real evaluation of the project and the TEAKS results with and without including the trust model. Only the three performance variables that are affected by the trust model are presented. As it was expected, the differences in the results when including and removing the model of trust are mainly noted in those agents that are assigned to work together in more than one task throughout the project (see e.g. team members 12 and 16 that are assigned to work together in four different tasks).

Nevertheless, in this specific scenario there were no many tasks where the same team members could interact together and no big differences were obtained in their performance when including or not the trust model. As the graphs in Figure 6.7 show, the most affected performance variable was the *level of collaboration* which presented a slightly improvement (by comparing with the real evaluation data) when the trust model is included. On the other hand, as it was also expected, the inclusion or not of the trust model did not affect the performance of those agents that were assigned to work alone in the tasks of the project (see for instance, team members 2 and 4).

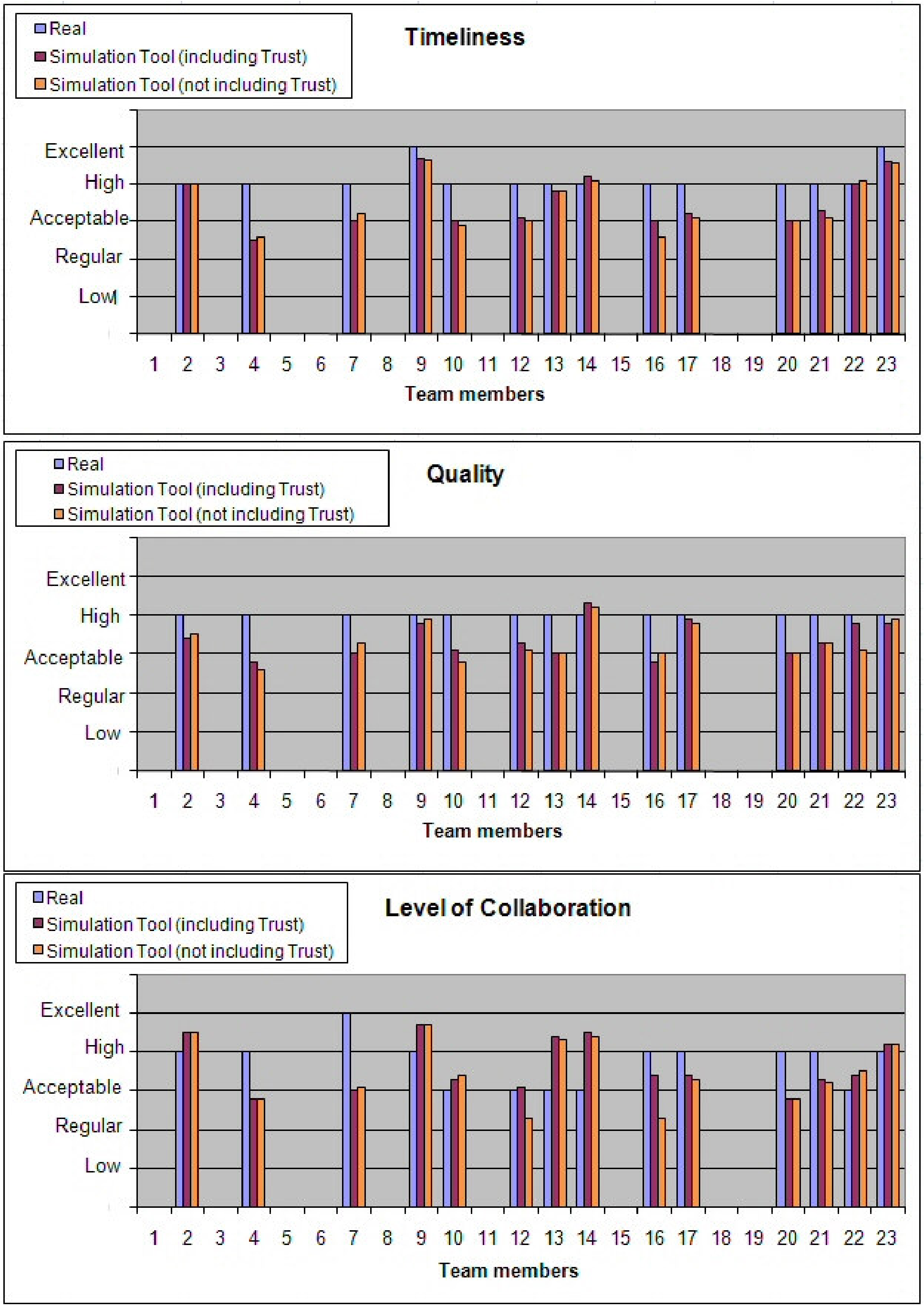


Figure 6.7. Comparison between TEAKS results –including and removing the model of trust– and the real evaluation data.

In terms of global performance the differences in the results were also minimal and mainly noted in those tasks performed by more than one team member that have been already interacted in previous tasks. See, for example, the *quality* value of the task "Design and programming of SQL queries - *Diseño y* *programación de consultas SQL*" and the *timeliness* value of the task "Design of SQL queries - *Diseño de consultas en SQL*" in the graphs of the Figure 6.8.

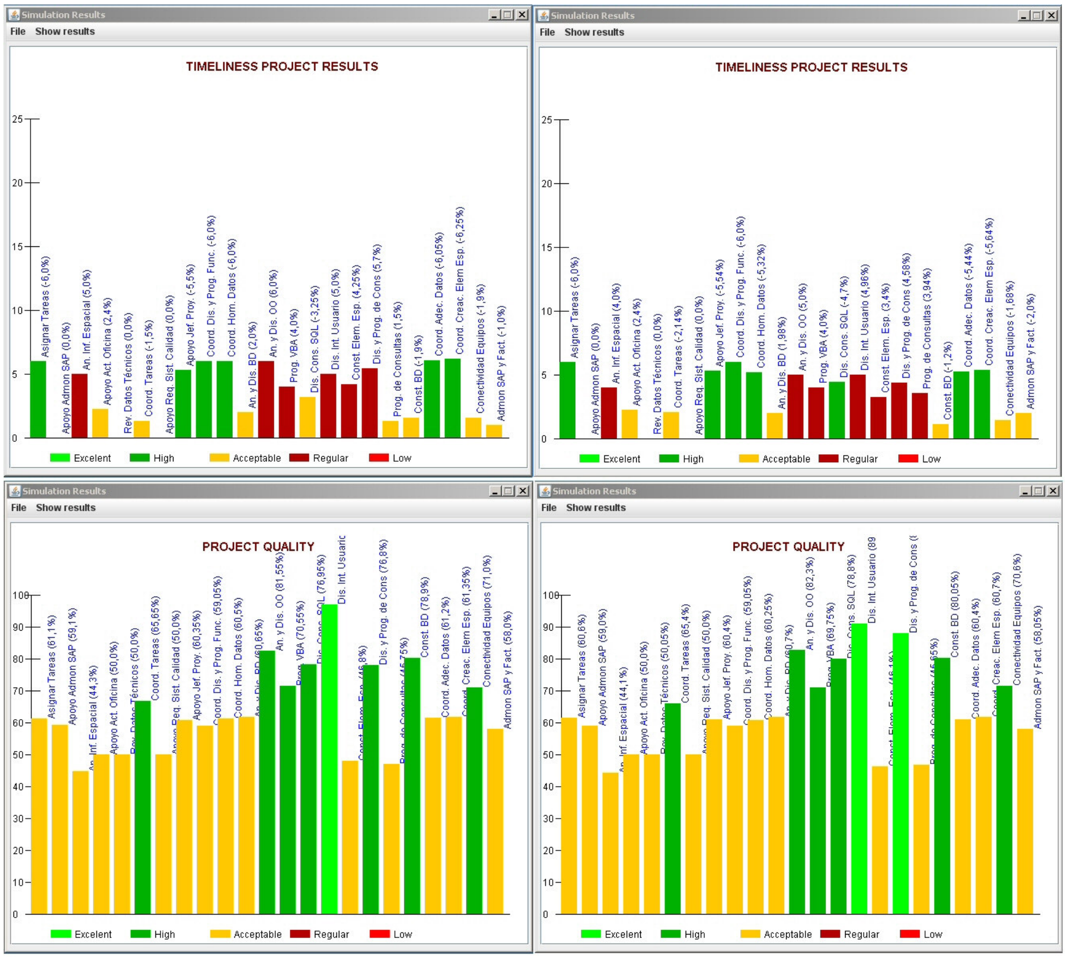


Figure 6.8. Comparison of the global work team performance including (left graphs) and excluding (right graphs) the TEAKS trust model.

The team members involved in both tasks had previously interacted in precedent tasks, allowing an evolution of the initial trust level and influencing the individual and global performance of the work team. In general terms, we can observe from these results that the work team performance is slightly better when excluding the trust model than when including it during the simulations. But a *better* performance does not mean *more realistic* results (i.e. a better foreseeing of the studied phenomena), as it can be observed from the individual performance results (see graphs in Figure 6.7), where the values obtained when including the trust model were closer to the real evaluation results than the values obtained when excluding the trust model.

Given the small number of tasks in the case study where the same team members interact together, we performed an additional experiment to analyse the effect of trust in the global work team performance. New 40 simulations with the same input data but setting the initial trust level of the team members to *low* instead to the default *medium* value were executed again. Additionally, in other 40 simulations the initial trust value was put to *high*. The results using the two different initial trust values can be shown in the graphs of the Figure 6.9.

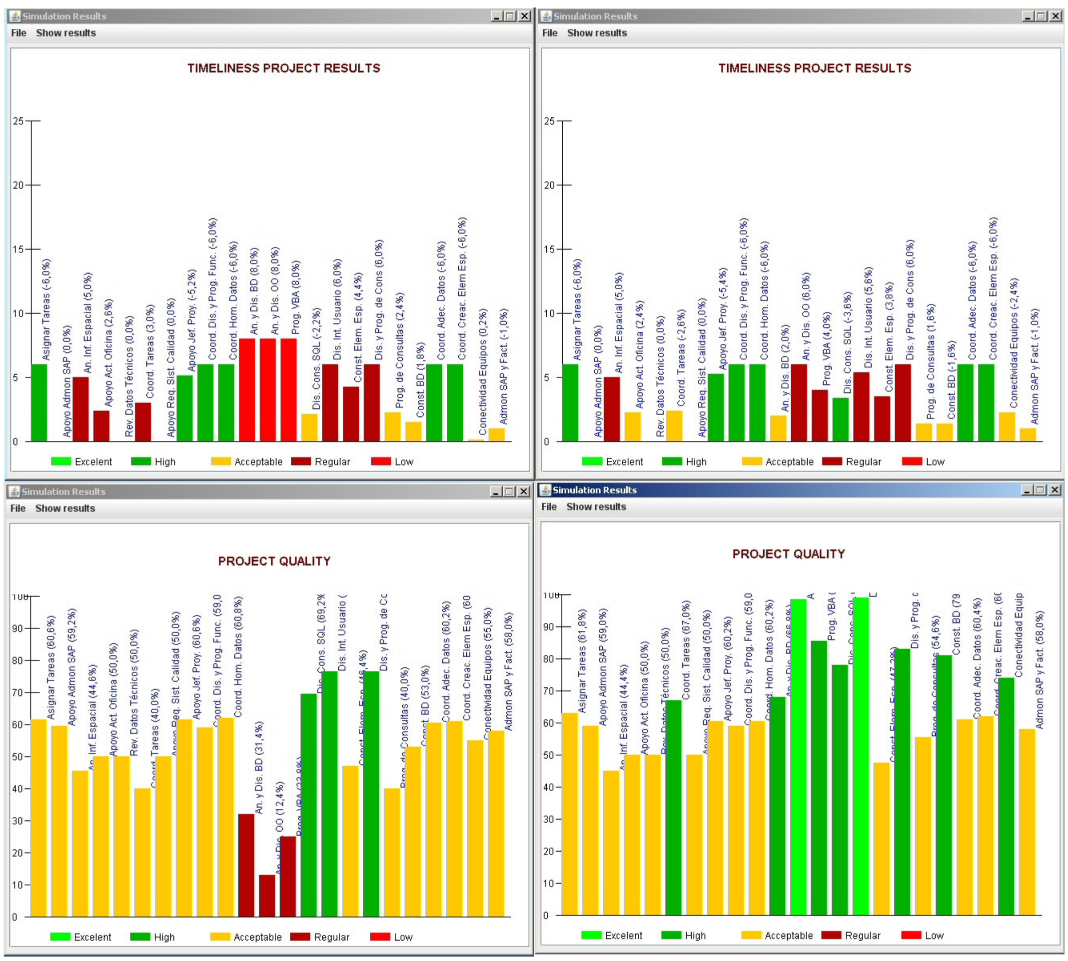


Figure 6.9. Global work team performance using *low* (left graphs) and *high* (right graphs) initial trust values in the team members.

When the initial trust value in the team members was set to *low*, the obtained global performance of the work team was worst than when using the default *medium* initial trust level. It was (unsurprisingly) observed that those tasks with the poorest performance (in terms of *regular/low* values in the *timeliness* and *regular* value in the *quality* variables) were those where several team members had to interact. On the other hand, when using a *high* initial trust level, the obtained global performance was slightly better than when using the default *medium* initial trust level, but in this case the difference was not so big, showing that lower values of trust had stronger negative effects over the performance in comparison to the positive effects obtained from high levels of trust.

One of the advantages found in the configuration of the real work team was the fact that several team members interacted with the same team mates in different tasks along the project. This situation allows us to trace the changes in the trust relationship for different team members and analyse the evolution of this social variable along the project. The graphs presented in the Figure 6.10 show the evolution of the trust level in the Agent 12 regarding its team mates in four different tasks: Agent 16, Agent 22 and Agent 23. The three graphs show the average of the defuzzified values in the trust variable after 40 simulations. Every graph corresponds to the evolution of trust using different initial values.

As it can be seen in the graphs, the evolution of trust in the Agent 12 regarding its three team mates was progressively increasing after the execution of every task when the initial value of trust was set to *medium* and *high*. The increment in the trust level was mainly influenced by the *high* and *excellent* quality values obtained in the four tasks where the team members interacted together. The lowest values of trust were obtained when the initial trust value was set to *low* and consequently, the two global performance values (*quality* and *timeliness*) obtained *regular* and *low* values in the four tasks. The corresponding (lower left) graph of Figure 6.10 shows that the increment in the trust level between the agents when using *low* values of trust is significantly lower than the increment when using the *medium* and *high* initial trust values. A similar evolution of trust was observed in all the other team members that interact in different tasks with the same team mates along the project.

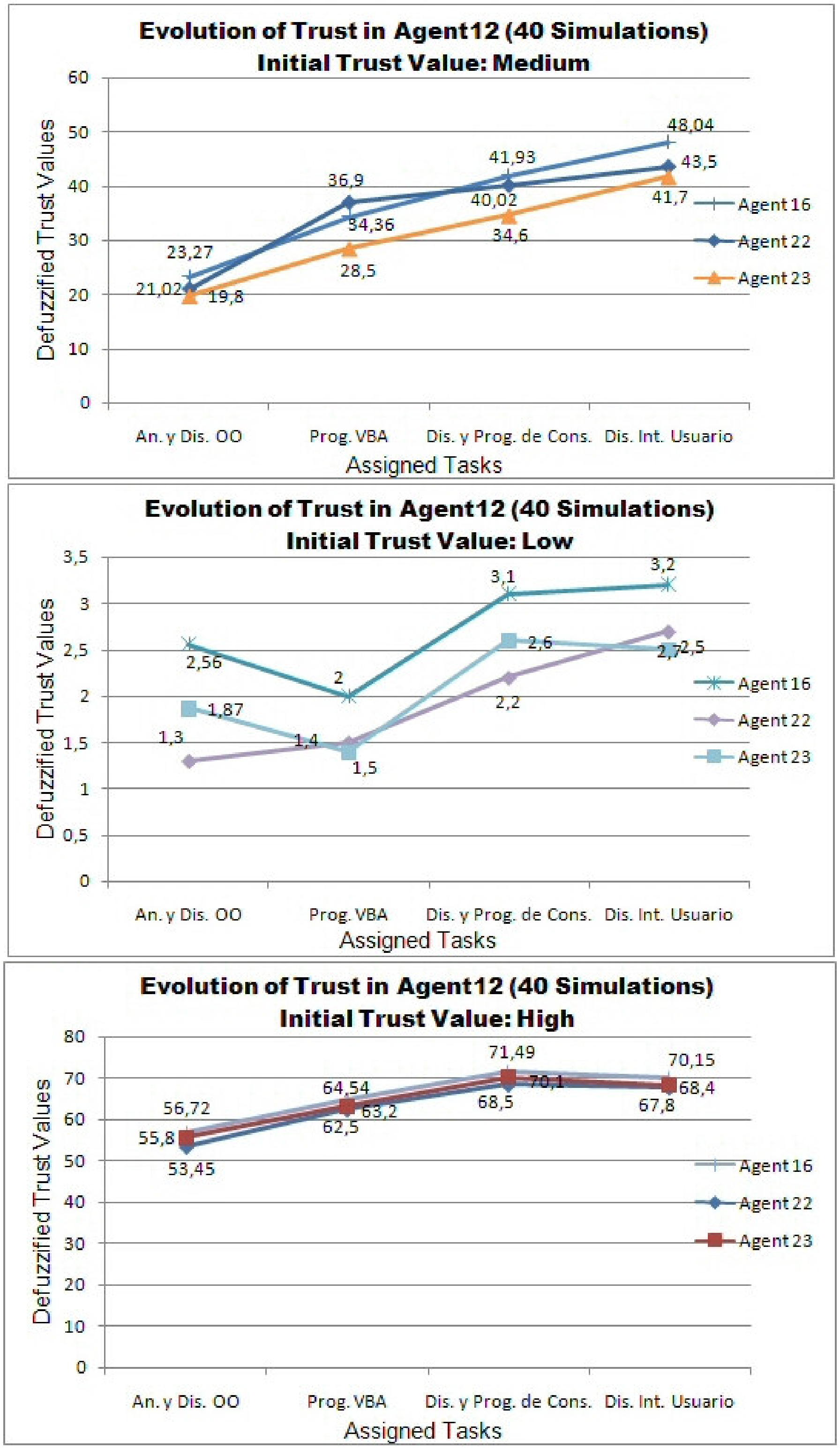


Figure 6.10. Example of trust evolution throughout the simulation using *medium* (upper graph), *low* (middle graph) and *high* (lower graph) initial trust values in the team members.

Although both the *face validity* and the *historical data validation* of the model were done using the *medium* initial trust value, different variations of trust to analyse the influence of this social skill variable at the individual and global performance in the work team were used. In general terms, it can be observed from these variations that *lower* values of trust affect negatively the performance of the work team, and although *medium* and *high* values of trust get positive performance in the work team, the differences when using these two last values were not highly relevant.

6.5. Discussion

The validation of TEAKS has been performed against a real work team configured with 23 people with different roles including the project manager, coordinator, specialists and technicians. Although the initial results are promising, the following limitations of the validation process need to be considered:

- The TEAKS model relies on the definition of a set of human attributes and the values of these attributes are a key input to generate the possible behaviour in the team members and get some estimated information over the individual and work team performance. As already mentioned, most of the values in the team members attributes used during the validation stage were obtained from a software containing standardised tests to identify styles of behaviour in the participants. Nevertheless, as the person in charge of applying this software to the workers commented, the information obtained from these tests can be considered just as a guide about the *general lines* of behaviour in an individual facing specific situations, but it does not guarantee at 100% the reactions nor the specific behaviour of a person in all the possible different scenarios while working in a task.

- The comparison between the TEAKS simulation results and the real evaluation records was done over 60% of the available data due to confidentiality matters. Even if 100% of the data were available, it is also important to note that the validation was performed using only one case study. In consequence, the suitability of the obtained results are applied to the project used as case study, but it is difficult to accept the generalisation of the model even to similar projects (i.e., project with similar characteristics in its tasks and assigned to a similar range in the number of the team members). Further evaluation tests of the model are necessary to confirm the initial results and identify the type of projects where the TEAKS model can be used as an adequate supporting tool.

- The real evaluation data of the team members' performance were obtained from evaluation forms filled by a single (or maximum two) person(s) at the end of the project: the project manager(s). This means that every team member's performance was evaluated according to the project manager perception and in some cases the project manager did not work directly with the team members during every task of the project. In such situations, as the project manager admitted, the evaluation of the individual performance was made taking as reference some indirect metrics such as the client satisfaction over the project final delivery.

Nevertheless the TEAKS simulation software and the initial results obtained from the case study were explained and discussed with several project managers and coordinators getting a positive evaluation and useful feedback. One of the useful received suggestions in terms of the software functionality (and that would be considered in further work) was the request to add a tool to modify the fuzzy rules defined in the model. Using this functionality, the project managers would be able to tune the influence of the model's variables over the team members' performance according to the particularities of the different types of projects. This suggestion was received from one of the IMP's project managers, who showed interest in the use of the TEAKS system in projects related with the exploration of deep waters or projects developed at petroleum platforms inside the sea. This type of projects involve the close interaction during large amount of time of several isolated people where emotions, trust and different personality types in the team members have higher influence on their performance than the cognitive capabilities.

A second interesting suggestion was to include, in each task of the project, a new quantitative attribute: the *estimated budget*. Having the estimated cost of each task, the global evaluation of the work team can be enhanced by calculating the possible *real* cost of each task taking into account their *delay/advance* obtained when running the simulations. Thus, if the estimated and the possible *real* cost of a task is available, some additional analysis such as the Earned Value Measurement [Fleming and Koppelman, 2005] can be done to provide information about differences in the budget of the project. Although the implementation of this type of analysis is an issue not directly related with the main topic of research in this thesis, it would be useful quantitative information that the software simulation tool can provide to project managers for the evaluation of the project.

6.6. Summary

The validation of the TEAKS model has been described in this chapter by performing the *face validity* and the *historical data* validation approaches in a real case of study developed at the Mexican Petroleum Institute (IMP). In the first part of the chapter, the data identified from the real work team and project to be used as the input data in the TEAKS simulation software were identified. Using this information, 23 agents were created facing a simulated project containing 23 tasks. The project used in this case study was the design, development and implementation of a Geographical Information System.

The historical data validation was done through the evaluation of the TEAKS results by comparing the obtained performance at the individual level from the TEAKS simulation software among the evaluation records of the participants in the real work team. Due to confidentiality matters, only the 60% of the evaluation records were accessible to perform the comparisons. Using the available information, the results showed good levels of similarity between the simulated and the real results in the performance metrics. In addition to the comparison of the results, the statistical information about the individual and work team performance generated by the TEAKS simulation tool were also analysed by project managers at the IMP. The results were found *interesting* and they state that the obtained data *resemble a part of the reality*. Some recommendations were made to the software to be applied for some specific type of projects.

The chapter also presents the analysis made over the *trust* relationship between the TEAKS agents to observe how the values in this attribute evolve throughout the simulated execution of the project and see the effect of trust in the work team performance.

The chapter concludes by discussing the limitations of the TEAKS validation process, which, although relevant, do not invalidate the assessment of the initial results of the TEAKS model, and allow the identification of further research directions, as it is explained in the last Chapter 7.

Chapter 7

Final Remarks

The work described in this dissertation is the result of some years of multi-disciplinary research where topics of different areas such as Multi-Agent Systems, Agent-based Simulation, Complex Systems, Psychology and Sociology were studied. These studies conducted to the design and implementation of an agent-based simulation model where software agents represent individuals in the context of a work team facing specific tasks of a project. The implementation of this model as a software simulation tool offers (mainly to project managers) a support in the decision-making of the formation and configuration of real work teams.

The following sections in this final chapter present a summary of the main contributions of this research and describe the potential future work to be done in order to improve the current achieved results.

7.1. Summary of Main Contributions

Regarding the objectives proposed in section 1.4, the TEAKS model developed for the purposes of the thesis provides a suitable tool for the analysis of the dynamics involved behind the individual behaviour within a work team. The model of these dynamics makes feasible the acquiring of statistical information about the possible performance of the participants in a work team, and in consequence, the global performance of the work team.

The development of the model that includes the identified dynamics behind individual and work team performance is the main theoretical contribution of this thesis. The identification of the individual and work team dynamics included in the model is based on the state-of-the-art from different research areas aimed to understand and to foster specific lines of human and team behaviour. Particularly, the Chapter 2 of this document presents a deep review of works where different theories present the importance of some specific individual and social attributes as main influences on the behaviour and work performance in individuals and groups.

As already stated, specific findings in these theories have been used to design the underlying architecture of the agent-based model presented in Chapter 3 and Chapter 4 where the individual and social attributes have been modelled through the use of fuzzy logic. This particular implementation is also an additional contribution by exposing the experiences gained in the use of fuzzy sets and fuzzy rules into TEAKS for making the representation of some of the internal attributes in the software agents and their relationships more realistic and suitable according to the modelled phenomenon.

The work developed in this thesis did not remain only in the theoretical contribution, but also in the implementation of the proposed model into a usable software simulation tool. The developed TEAKS simulation software allows to the target users the analysis of different work teams' configuration through the experimentation by changing or replacing specific individual and social dynamics encapsulated in the TEAKS agents. Changing and modifying the modelled individual and social dynamics support the understanding and answer to specific questions (such as those listed in the section 1.2 of Chapter 1) regarding the influences of the different attributes in the final behaviour and performance generated within a work team.

This thesis also contributes to the research community by reporting the experiences acquired during the validation stage of the model. The validation process was done using two approaches: the *face validity* and *historical data validation,* both developed using a real scenario in a large company. Although with some important limitations, the results obtained from the validation stage have allowed to identify the strengths of the proposed model as well as some future directions of work to be directed in order to improve the current TEAKS model.

7.2. Future Work

The modelling of human behaviour, even in a well defined context, will always generate a myriad of open issues to work on for a better and more complete model. In the context of the TEAKS model presented in this thesis, the following activities are just a representative set of the future work that can be carried on.

In the TEAKS model, the cognitive capabilities that have been modelled in the agents are seen as *static* attributes throughout the simulated completion of the project. Nevertheless, there is evidence that in real life these cognitive capabilities evolve in time. In concrete, current research in Organisational Creativity has shown that creative behaviour in individual highly depends on the conditions offered by the team or organisational context where the person is immerse. Contexts that foster creativity entail high degrees of *challenging work*, *autonomy*, *workgroup supports* [Amabile et al., 1996], and *constructive feedback* [Zhou, 2008]. In consequence, the level of creativity modelled in the TEAKS agents can be improved by including specific contextual characteristics (e.g. including new task's attributes and adding a new model where specific and important characteristics of the work team's organisation are represented) that allow some variations (increasing/decreasing) in the initial creativity level of a team member. Using an improved model of individual creativity jointly with the current modelled social, emotional and personality styles, the concept of *team creativity* (and its consequences in the work team performance) can be modelled by aggregation processes across the individual characteristics and the simulated elapsed time during the project completion [Pirola-Merlo and Mann, 2004].

Other important aspect to consider is to improve the effect that the team member's role has on the global work team. Currently, in the TEAKS model the different team member roles are mainly used as a moderator attribute, jointly with the personality styles, between the required specialisation and difficulty level of the assigned task(s) and the emotional state of the team member. Nevertheless, it would be also important not only to include the *technical* roles of the team members, but also some *social roles* such as the *team leader*. Recent studies have shown the importance of an effective leader has over the cohesion, goal selection, goal attainment, and in consequence on the performance of the work team [Trent, 1996].

An additional promising area of improvement in the current model would be the extension of the model of trust. As indicated in the section 4.3.3 of Chapter 4, the initial trust level between the team members (i.e. at the beginning of the project) is set to the *medium* default value. This initial value intends to represent no previous interaction between the team members in past projects. Nevertheless, recent studies have demonstrated the importance of prior social capital between members in the development of initial trust in teams. In teams with high prior social capital, trust evolves from previous experience and current perceptions of attributes and behaviours of the trustee. On contrary, in teams with previously low social capital, the initial trust level seems to develop mostly through team members' own disposition or propensity (e.g. derived from their personality style) to trust others [Costa et al., 2009]. These studies also found that teams with high prior social capital cooperate more and perform better than team with low prior social capital. Thus, it would be interesting to include in the TEAKS model the *social capital* from previous interaction between the candidates to form the new work team that directs the initial trust relationship between them.

But not only the theoretical model is susceptible of improvements. In terms of the TEAKS simulation tool, an interesting functionality would be a mechanism to allow the user to tune the current rules that generate the behaviour in the agents. Such a mechanism would provide the *personalisation* in some degree, to projects with specific particularities like those mentioned by the project managers at IMP (see last part of section 6.5 in Chapter 6) where the emotional and social attributes have strongest influence in the team performance (and even in the team survival) than the cognitive capabilities.

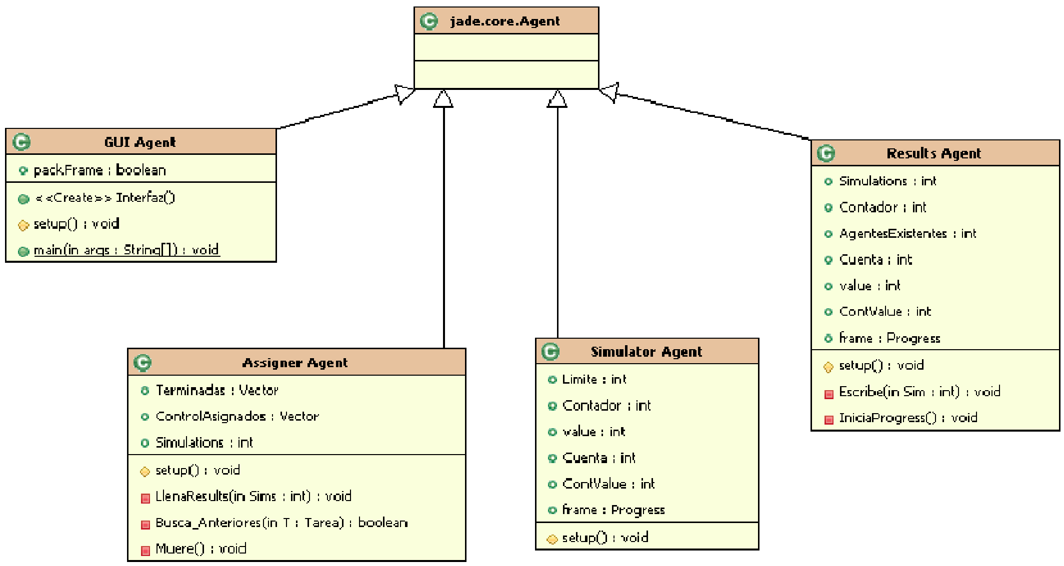
Other line of development that can contribute to better represent real project scenarios in the TEAKS simulation is the inclusion of a mechanism that randomly introduces certain amounts of delays (independent of the *normal* delays produced by the team members performance) in the task timeliness attribute during the execution of the simulations. These delays in tasks would represent the effect of some external factors, such as new requirements of the client, new policies introduced by the institutions (the own company and/or Government), that in most of the cases have negative consequences in the schedule and budget of the project. A feature of this type in the simulation, jointly with the inclusion of the estimated cost for each task (as explained in the last paragraph of section 6.5 in Chapter 6), can provide more information to project managers to get a global evaluation of the modelled project. Moreover this would open new perspectives to develop in the TEAKS model some research about risk measurement, similarly to the work of [Pajares and López-Paredes, 2008].

Last but not least is the development of a stronger validation process. Although the validation of a model (and especially when the model includes the representation of human beings through the settings of sensible information) using available data from a real scenario is complex and time-consuming, the evaluation of the TEAKS model would be enriched by comparing the obtained results against new cases of study. This should remove the current limitations found during the validation stage and would identify new and interesting challenges to address in the modelling of work teams.

7.3. Summary

The summary of the main achieved contributions and the open issues are described in this final chapter. In particular the theoretical and practical contributions reached through this thesis have been explained. Additionally, some future work has been described towards the improvement of the model. Additional implementation and validation activities have also being mentioned as promising further activities to perform beyond the work described in this thesis.

Appendix A. Class diagrams of the TEAKS Agents



TEAKS System agents classes

TEAKS Team member agents class, including the behaviour class

Appendix B. Performance Evaluation Form Used at IMP

IMP

EVALUAR EL DESEMPEÑO DEL PERSONAL

IMP

DATOS DEL EVALUADO:
NOMBRE [redacted] CLAVE [redacted] NIVEL [redacted]
CATEGORIA [redacted] COMPETENCIA TECNOLOGIAS DE INFORMACIÓN

DATOS DEL JEFE DE PROYECTO
NOMBRE [redacted] CLAVE [redacted] NIVEL [redacted]
CATEGORIA [redacted] COMPETENCIA TECNOLOGIAS DE INFORMACION

DATOS DEL PROYECTO
NUMERO [redacted] NOMBRE [redacted]
FECHA DE INICIO [redacted] FECHA DE TERMINO [redacted]

1. CUMPLIMIENTO DE METAS		CALIFICACION	
Grado de cumplimiento y alcance individual de los objetivos planteados en el desarrollo de un proyecto	20 %	Muy bajo	
	40 %	Bajo	
	60 %	Mínimo	
	80 %	Promedio	
	100 %	Satisfactorio	X

2. OPORTUNIDAD DE RESULTADOS		CALIFICACION	
Entrega de resultados en el tiempo y con la calidad programados, integra información confiable y oportuna de acuerdo a los datos solicitados	BAJO	Los resultados presentados no corresponden en tiempo y calidad a lo solicitado	
	REGULAR	Esfuerzos insuficiente en la realización de sus actividades, cumple en forma mínima con los resultados de trabajo	
	PROMEDIO	Resultados satisfactorios, la calidad y el tiempo de entrega generalmente son adecuados	
	ALTO	Resultados confiables y oportunos en el tiempo estipulado y la calidad requerida	X
	EXCELENTE	Resultados sobresalientes en tiempo y calidad de los trabajos solicitados	

3. COLABORACION Y PARTICIPACION EN EQUIPO		CALIFICACION	
Grado de participación, integración y colaboración en grupos de trabajo para el desarrollo de proyectos	BAJO	Poca participación en equipos de trabajo obstaculizando el logro de objetivos comunes	
	REGULAR	Mediana participación e integración en equipos de trabajo permitiéndole alcanzar objetivos en forma limitada	
	PROMEDIO	Mantiene un nivel aceptable de relaciones de trabajo, colaborando en las actividades que le corresponden y apoya el cumplimiento de los objetivos comunes del proyecto	
	ALTO	Participa en forma proactiva dentro del equipo de trabajo y tiene alta disponibilidad para colaborar con otros en tareas comunes	X
	EXCELENTE	Sobresale por su gran participación y colaboración en los equipos de trabajo y generalmente promueve el logro de objetivos comunes	

4. CONTRIBUCION INDIVIDUAL AL PROYECTO		CALIFICACION	
Aportaciones individuales hechas por los integrantes del proyecto tomando en cuenta la contribución operativa en el desarrollo del proyecto, así como las aportaciones creativas e innovadoras propuestas adicionalmente	BAJO	Su contribución es limitada y siempre bajo solicitud expresa	
	REGULAR	Las contribuciones individuales que realiza son las mínimas solicitadas	
	PROMEDIO	Las aportaciones hechas en el desarrollo del proyecto son las esperadas	
	ALTO	Los resultados individuales obtenidos sobrepasan las expectativas esperadas, adicionalmente presenta y promueve mejoras a los proyectos	
	EXCELENTE	Personal con gran iniciativa, creatividad e innovación que supera en gran medida las aportaciones individuales esperadas	X

5. CALIDAD DEL TRABAJO ENTREGADO		CALIFICACION	
Grado de cumplimiento en los estándares establecidos para el proyecto	BAJO	Los trabajos entregados presentan deficiencias que impiden cumplir con el mínimo de estándares solicitados	
	REGULAR	Cumple en forma mínima con los estándares requeridos para el trabajo	
	PROMEDIO	El trabajo entregado generalmente cumple con los estándares requeridos	
	ALTO	Cumplimiento total de la calidad esperada en sus trabajos	X
	EXCELENTE	Supera las expectativas y estándares del trabajo solicitado	

6. NIVEL DE SUPERVISION REQUERIDO			
Grado de independencia y autonomía de gestión en la operación y realización diaria de las actividades encomendadas	PERMANENTE	Necesita una supervisión constante y directa con ayuda de terceros para realizar bien su trabajo	
	PERIODICA	Requiere de supervisión en periodos específicos de entrega de trabajos o cuando se le asignan nuevas actividades	
	EVENTUAL	Supervisión específica al termino de las tareas o acciones encomendadas	X
	NO REQUIERE	Realiza sus trabajos en forma autónoma sin requerimiento de supervisión	

REVISIÓN

[redacted]
(NOMBRE Y FIRMA DEL JEFE DE PROYECTO)

CO-F10 Rev. 4 CO-01-04-01

Appendix C. Example of the Behaviour Rules in the TEAKS Agents Implemented with JESS.

```
; DEFINITION OF THE FUZZY SETS FOR THE INPUT VARIABLES

(defglobal ?*FExperience* = (new nrc.fuzzy.FuzzyVariable "experience" 0.0
100.0))
(defglobal ?*FDriver* = (new nrc.fuzzy.FuzzyVariable "driver" 0.0 100.0))
(defglobal ?*FExpressive* = (new nrc.fuzzy.FuzzyVariable "expressive" 0.0
100.0))
(defglobal ?*FAmiable* = (new nrc.fuzzy.FuzzyVariable "amiable" 0.0 100.0))
(defglobal ?*FAnalytical* = (new nrc.fuzzy.FuzzyVariable "analytical" 0.0
100.0))
(defglobal ?*FAloneTeam* = (new nrc.fuzzy.FuzzyVariable "aloneteam" 0.0
100.0))
(defglobal ?*FIntExt* = (new nrc.fuzzy.FuzzyVariable "introverted" 0.0 100.0))
(defglobal ?*FDuration* = (new nrc.fuzzy.FuzzyVariable "duration" -30.0 30.0))
(defglobal ?*FTaskType* = (new nrc.fuzzy.FuzzyVariable "tasktype" 0.0 100.0))
(defglobal ?*FTaskDifficult* = (new nrc.fuzzy.FuzzyVariable "taskdifficult"
0.0 100.0))

; DEFINITION OF THE FUZZY SETS FOR THE OUTPUT VARIABLES
(defglobal ?*ChangeDesire* = (new nrc.fuzzy.FuzzyVariable "ChangeDesire" -30.0
30.0 "Intensity"))
(defglobal ?*ChangeInterest* = (new nrc.fuzzy.FuzzyVariable "ChangeInterest" -
30.0 30.0 "Intensity"))
(defglobal ?*ChangeDisgust* = (new nrc.fuzzy.FuzzyVariable "ChangeDisgust" -
30.0 30.0 "Intensity"))
(defglobal ?*ChangeAnxiety* = (new nrc.fuzzy.FuzzyVariable "ChangeAnxiety" -
30.0 30.0 "Intensity"))


; RULES THAT AFFECT THE EMOTIONAL STATE

(defrule high_advance_duration_high_driver
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (driver ?dr&:(fuzzy-match ?dr "High"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Equal"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "Up"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "Equal"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "Equal"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH HIGH DRIVER PERSONALITY; ")
  )
)


(defrule high_advance_duration_medium_driver
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (driver ?dr&:(fuzzy-match ?dr "Medium"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Up"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "Up"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "Equal"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "Down"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH MEDIUM DRIVER PERSONALITY; ")
  )
)
```

```
(defrule high_advance_duration_low_driver
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (driver ?dr&:(fuzzy-match ?dr "Low"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Up"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "HighUp"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "Equal"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "Equal"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH LOW DRIVER PERSONALITY; ")
  )
)


(defrule high_advance_duration_high_expressive
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (expressive ?exp&:(fuzzy-match ?exp "High"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Up"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "Up"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "Equal"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "HighDown"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH HIGH EXPRESSIVE PERSONALITY; ")
  )
)


(defrule high_advance_duration_medium_influence
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (expressive ?exp&:(fuzzy-match ?exp "Medium"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Up"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "Equal"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "Equal"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "Equal"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH MEDIUM EXPRESSIVE PERSONALITY; ")
  )
)


(defrule high_advance_duration_low_influence
  (and (advance ?a&:(fuzzy-match ?a "HighAdvance"))
       (expressive ?exp&:(fuzzy-match ?exp "Low"))
  )
 =>
  (assert (change_desire (new FuzzyValue ?*ChangeDesire* "Up"))
          (change_interest (new FuzzyValue ?*ChangeInterest* "Up"))
          (change_disgust (new FuzzyValue ?*ChangeDisgust* "HighDown"))
          (change_anxiety (new FuzzyValue ?*ChangeAnxiety* "Down"))
  )
  (bind ?*rulesThatFired* (str-cat ?*rulesThatFired*
        " HIGH ADVANCE IN THE TASK WITH LOW EXPRESSIVE PERSONALITY; ")
  )
)
```

Appendix D. Publications Originated from this Thesis

The work presented in this thesis has been published and presented in the following journals and conferences:

I) Papers in Journals

- Martínez-Miranda J., Pavón J. (2010): ***Modelling the Influence of Trust in Work Teams Performance.*** Submitted and currently under review in SIMULATION: Transactions of The Society for Modelling and Simulation International.

  Abstract. The suitable selection of people to configure a successful work team is not a trivial decision-making process due to the diversity and complexity of the factors that influence each individual and team performance. Nowadays most of the team formation processes are typically performed by the project managers based on past experience and available (though frequently scarce, uncertain and dynamic) information about personal and professional characteristics of the potential team members. We introduce an agent-based model developed to support this decision-making process where a virtual team can be configured using some selected characteristics of the real team candidates. Fuzzy sets and fuzzy rules are used to model the interaction between the team members and a given set of tasks generating statistical information that represent the possible performance of the team-members.

  More specifically, the paper focuses on the concept of trust, a relevant social skill that influences performance at individual (team member) and global (work team) level. We describe the implementation of an agent-based simulation system where the user can test different team configurations to compare performance and select the best possible work team for a given project. The evaluation and validation of the model has been performed through face validity and historical data validation techniques, which base on collected information from a real work team. The results show the suitability of the model as a helpful tool in the formation and configuration of work teams for specific scenarios.

- Martínez-Miranda J., Aldea A. (2005): ***Emotions in Human and Artificial Intelligence***. Computers in Human Behaviour, Vol. 21(2), pp. 323-341. March 2005. DOI: 10.1016/j.chb.2004.02.010

  Abstract. Intelligence and emotions differentiate humans from animals. Emotion is part of a person's behaviour and certain feelings can affect his/her performance, emotions can even prevent a person from producing an intelligent outcome. Therefore, when a computer aims to emulate human behaviour, not only should this computer think and reason, but it should also be able to show emotions. This paper presents a review of recent research that shows the importance of the emotions in human intelligence. This paper also presents the research that has been carried out into the incorporation of emotions to intelligent systems, how a computer can show affections and how to create intelligent agents that show emotions to other agents that communicate with them in the same environment.

- Aldea A., Bañares-Alcántara R., Jiménez L., Moreno A., Martínez-Miranda J., Riaño D. (2004): ***The scope of application of multi-agent systems in the process industry: three case studies***. Expert Systems with Applications, Vol. 26(1), pp. 39-47, January 2004. DOI: 10.1016/S0957-4174(03)00105-2

Abstract. It has been suggested that multi-agent systems (MAS) are specially adequate for the solution of problems with a dynamic, uncertain and distributed nature. Within industrial applications, there is a wide spectrum of problems with these characteristics, in particular those covering the modelling of artifacts, methodologies and organisations. Three case studies on the application of MAS in the process industry are presented. All of them relate to tools that are being developed to support very diverse core tasks in the process industry (and, by extension, the petroleum industry):

- An intelligent search system composed of Internet information agents which are able to gather, compile and classify data available in web pages related to a specific technological domain. This search engine is the first step towards the construction of a knowledge management platform that will allow chemical process industries to improve their capabilities to monitor, predict and respond to technological trends and challenges.

- A system to support the concurrent design of processes, to ease communication between engineers who perform design and keep them informed about the progress of the design process.

- A tool to support the configuration of work teams. This tool will assist in the configuration of the most suitable team for a specific project. It takes into account the ideal size of the team (2 to n members); its specific composition (managers, engineers/scientists, assistants, etc.); and the proposed type of organisation (centralised, tree hierarchy, etc.).

These case studies are representative of a large variety of the possible applications of agent based systems in the process industry.

- Martínez-Miranda J., Aldea A., Bañares-Alcántara R. (2004): ***Agent Based Simulation in the Selection of Work Teams***. Computación y Sistemas – Iberoamerican Journal, Vol. 7(3), pp. 210-223, January-March, 2004.

Abstract. When a new project starts in Industry, the correct selection of people to integrate a work team in order to develop that project is not trivial. The success of a project is greatly due to the personal responsibility of each member, but also to an adequate communication, collaboration and co-operation between the individual team members. In addition we consider that emotions play a critical role in rational decision-making, perception, human interaction, and human intelligence. Nowadays, the team selection process is typically done by one person(a manager) based on his/her past experience and his/her own information about the people's competence and availability. We present an Agent-based model to simulate the human behaviour in a work team and a first prototype that implement it. Some initial results are discussed and the future work is presented.

II) Papers in Book Collections

- Martínez-Miranda J., Aldea A., Bañares-Alcántara R. (2003): ***A tool to support the configuration of work teams***. Process Systems Engineering (Part B), Chen B., Westerberg A. (Eds.), pp. 280-285, Elsevier, 2003.

  Abstract. One of the initial steps of an industrial project is the configuration of the team(s) that will execute it. The correct selection of people to integrate a team within a complex engineering project is not a trivial task. Team configuration is a type of Business Decision-Making typically done by one person (a manager) based on his/her past experience and the available information about the behaviour and interaction between the potential team members. In this work we propose a tool that provides information about the possible overall behaviour of a work team. This tool uses Artificial Intelligence techniques, specifically, Multi-Agent Systems (MAS) technology. We present the first results obtained with this prototype tool and discuss some future developments to improve them.

III) Papers in Peer-Review Conferences

- Martínez-Miranda J., Pavón J. (2010): ***Human Attributes in the Modelling of Work Teams.*** In the 9th IFIP International Conference on Information Technology for Balanced Automation Systems (BASYS 2010) – Advances in Information and Communication Technology, Vol. 322/2010, pp. 276-284, Springer-Verlag.

  Abstract. This paper presents a summary of relevant research findings that have been used as the theoretical background in the design of an agent-based model to simulate the human behaviour within work teams (the TEAKS model). It underlines some of the main trends in the modelling of human behaviour in teams, and the rationale for selecting the attributes to represent real team candidates as software agents in the TEAKS model.

- Martínez-Miranda J., Pavón J. (2009): ***Modelling Trust into an Agent-Based Simulation Tool to Support the Formation and Configuration of Work Teams.*** In the 7th International Conference on Practical Applications of Agents and Multi-Agent systems (PAAMS 2009) – Advances in Soft Computing, Vol. 55/2009, pp. 80-89, Springer-Verlag. DOI: 10.1007/978-3-642-00487-2

  Abstract. One important factor that contributes to create good or bad relationships between individuals inside human societies is the notion of trust. In particular, some research works have proved the influence of trust in the performance of the activities that team-members perform jointly. This paper presents our initial theoretical work to include the trust factor into our TEAKS (TEAm Knowledge-based Structuring) model. TEAKS is an agent-based model to simulate the interaction between individuals when working together in the development of a project. Each team-member is represented through a set of pre-selected human characteristics: the emotional state, social characteristics, cognitive abilities, and personality types. The main outcome of the TEAKS simulation is statistical information about the possible performance at the individual and team levels. In this context we use two (emotional state and personality traits) of the four modelled human characteristics to introduce a model of trust into

TEAKS to analyse the impact of trust in the results of the team.

- Martínez-Miranda, J., Pavón, J. (2008): ***An Agent-Based Simulation Tool to Support Work Teams Formation***. International Symposium on Distributed Computing and Artificial Intelligence (DCAI 2008) - Advances in Soft Computing Vol. 50/2009, pp. 80 – 89. Springer-Verlag. DOI: 10.1007/978-3-540-85863-8

Abstract. The team configuration process is typically performed by a manager based on past experience and available (though frequently scarce, uncertain and dynamic) information about the cognitive, personal and social characteristics of the potential team members. To support this decision-making process we propose an agent-based model where a virtual team can be configured using the characteristics of the real candidates to form the team, and given a set of tasks, the model generates the possible performance of the team-members. The model is based on Fuzzy Set Theory and Fuzzy Logic and it has been validated with an industrial project involving 23 team members and 23 tasks. The architecture of the model and the initial results are presented in this paper.

- Martínez-Miranda, J., Aldea, A., Bañares-Alcántara, R., Alvarado, M. (2006): ***TEAKS: Simulation of Human Performance at Work to Support Team Configuration***. In Proceedings of 5th Conference on Autonomous Agents and Multiagent Systems (AAMAS 2006), pp 114-116. Peter Stone and Gerhard Weiss (Eds.) ACM Press. DOI: doi.acm.org/10.1145/1160633.1160649

Abstract. The management of a complex engineering project is a difficult task that initially involves the division of the project into tasks; the selection of the right people; and the correct allocation of those tasks for the selected people. Team configuration process is typically performed by a manager based on his/her past experience and the available (though frequently scarce, uncertain and dynamic) information about the cognitive, personal and social characteristics of the potential team members. To support this decision-making process we propose TEAKS, a knowledge-based tool that given an initial team configuration and a set of tasks, simulates the most possible team performance. Its formal bases are Fuzzy Set Theory and Fuzzy Logic and it is implemented using Multi-Agent Systems technology in Java, JADE, JESS and FuzzyJESS. This tool was validated with an industrial project involving 23 team members and 23 tasks (ranging from task assignment to SAP administration, SQL programming and equipment connectivity).

- Martínez-Miranda, J., Alvarado, M., Aldea, A., Bañares-Alcántara, R. (2005): ***Industrial validation of a system to support the configuration of teams***. In Proceedings of the 7th World Congress of Chemical Engineering, 10-14 July, Glasgow 2005. ISBN: 085295-494-8.

Abstract. The configuration of a team within a complex engineering project is a difficult task involving the selection of the right people and their assignment to the right tasks at the right time during the progress of the project. The success or failure of a project depends critically on this task. This decision making process is typically performed by a manager based on his/her past experience and the available (though frequently scarce, uncertain and dynamic) information about the cognitive, personal and social characteristics of the potential team members.

TEAKS is a knowledge-based tool supporting this process through the generation of a set of likely scenarios given a team configuration and a set of tasks. Its formal bases are Fuzzy Set Theory and Fuzzy Logic and it is implemented using Multi-Agent Systems technology in Java, JADE, JESS and FuzzyJESS. Because the value of each fuzzy parameter is determined through a probability distribution at each run, the results of the simulations are non-deterministic.

Each team member is represented by a JADE agent accounting for his/her social, cognitive and emotional characteristics, and personality traits (21 in total). In turn, each task is described in terms of 9 properties such as complexity, deadline and cost. With this information TEAKS simulates the interaction between the different team members and also between members and their assigned task(s). The performance of a member with respect to a task is measured in terms of 6 parameters, e.g. goal satisfaction, timeliness of results and individual contribution.

The system has been validated with an industrial project in the area of Petroleum, Gas and Basic Petrochemistry involving 23 team members (a project leader, a coordinator, 5 senior specialists, 10 junior specialists and 6 technicians) and 23 tasks (ranging from task assignment to SAP administration, SQL programming and equipment connectivity).

- Martínez-Miranda, J., Aldea, A., Bañares-Alcántara, R. (2004): ***Modelling Human Behaviour to Support the Integration of Work Teams***. In Proceedings of the Mexican International Conference on Artificial Intelligence (MICAI, 2004), Workshop on Intelligent Computing, WIC 2004. April 2004 Mexico City.

Abstract. One of the most important steps when a new project starts in Industry is the correct selection of people to integrate a work team. The success of that new project is greatly due to the personal responsibility of each member, but also to an adequate communication, collaboration and co-operation between the individual team members. In addition human emotions play a critical role in rational decision-making, perception, human interaction, and human intelligence. Nowadays, the team configuration process is typically done by the project(s) manager(s) based on his/her past experience and his/her own information about the people's competence and availability. This paper presents part of my Ph.D. research work in order to help to solve this problem. I use an agent-based model with fuzzy logic to simulate the human behaviour in a work team. A first prototype that implements this model is presented and some initial results are discussed. Finally the future work is presented.

- Martínez-Miranda, J., Aldea, A., Bañares-Alcántara, R. (2003): ***Simulation of work teams using a Multi-Agent System***. In Proceedings of the Second International Joint Conference on Autonomous Agents and Multi Agent Systems, (AAMAS 2003), pp. 1064-1065. July 2003. DOI: doi.acm.org/10.1145/860575.860797

Abstract. When a complex project starts in industry the selection of team(s) is one of the first steps that must be done. The correct selection of people to integrate a team within a complex engineering project is not a trivial task. Team configuration is a type of business decision-making typically done by a manager based on his/her past experience and with the available information about the behaviour and interaction between the potential team members. In this work we propose a Multi-Agent System that provides information about the possible overall behaviour of a work team and present the first results obtained.

- Martínez-Miranda, J., Aldea, A., Bañares-Alcántara, R. (2002): ***A Social Agent Model to Simulate Human Behaviour in Teamwork***. In Proceedings of the 3rd Workshop on Agent-Based Simulation, pp. 18–23. Passau (Germany), April 2002. ISBN: 3-936150-17-6.

  Abstract. In every complex project that involves many people working together, the search of the best possible team is crucial. The correct selection of people to integrate a team with a particular objective is not something trivial. We believe that a Multi-Agent System is suitable to simulate human social behaviour, in particular to simulate a team working together to achieve a common goal. In this paper we present our first research in the use of MAS to simulate the expected behaviour in a teamwork. Three different aspects of social agents have been investigated: teamwork simulation, emotions/personality models, and social simulation with agents. The area of application is the selection of people to integrate a team in charge of the conceptual design of a chemical process.

- Martínez-Miranda, J., Aldea, A., Bañares-Alcántara, R. (2001): ***Agentes Autónomos para Simular el Comportamiento Humano en un Equipo de Trabajo***. (in Spanish). Open Discussion Track Proceedings of the VIII Iberoamerican Conference on Artificial Intelligence, IBERAMIA 2002. Sevilla (Spain). Garijo F., Riquelme J.C., Toro M. (Eds.), pp. 1-10. November 2002. ISBN: 84-95499-87-8.

  Abstract. Cuando en un proyecto complejo es necesaria la integración de varias personas para llevar a cabo este proyecto, siempre se intentará seleccionar el mejor equipo posible. La integración adecuada de personas para formar un equipo de trabajo que tenga un objetivo en común no es una tarea fácil. El paradigma de los sistemas multi-agentes (SMA) dentro de la Inteligencia Artificial es uno de los más adecuados para simular el comportamiento humano, utilizando a un agente como representante de una persona. En este articulo presentamos nuestra primer investigación en el uso de los SMA para simular el comportamiento que podría presentar un equipo de trabajo durante el desarrollo del proyecto. Tres áreas de los SMA se utilizarán para la consecución de este objetivo: formación y simulación de equipos, modelado de emociones y personalidades, y características sociales en los agentes. Se toma como caso de estudio un equipo de trabajo encargado de llevar a cabo tareas de diseño conceptual de procesos químicos.

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