A SOLUTION TO PRISON OVERCROWDING AND RECIDIVISM: GLOBAL POSITIONING SYSTEM LOCATION OF PAROLEES AND PROBATIONERS

-- Innovative Tracking Systems --

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ABSTRACT

The research of the Innovative Tracking Systems team focuses on location and data management technology for use in the criminal justice system, with an emphasis on monitoring probationers and parolees. Faced with an overwhelming prison population and an unprecedented amount of people recently released from prison, the need to curb recidivism is stronger than ever before. A Global Positioning System (GPS) based technological solution will better equip corrections officers to monitor offenders in the community and also provide a highly visible deterrent. This thesis explores the philosophy of incarceration and parole, current trends in correctional manpower and technology, officer burnout, case law, and privacy concerns. Specific evaluation is made of existing and on-the-horizon location technology for use in probation monitoring. In light of current problems in the corrections field, the thesis proposes and evaluates the efficacy of a novel technology – the Sentinel Location System - for use in probationer and parolee monitoring programs.

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DEFINITIONS:

GENERAL

- JAIL: An adult confinement facility administered by local law officials that holds persons detained pending adjudication and persons committed for sentences of one year or less.[1]

- PAROLE: The release of an offender into the community prior to the expiration of his sentence, subject to conditions imposed by a judicial official.[2] Parole programs mirror the approaches to probation defined above.

- PRISON: A confinement facility having custodial authority over adults sentenced to confinement for one year or more.[3]

- PROBATION**:** A nonincarcerative criminal sentence that places an offender under the supervision of an agent of the court and subject to behavioral requirements. The six main types of probation are:
  - Standard: The rules of standard probation include:[4]
    - Commit no offense against the law
    - Avoid injurious or vicious habits
    - Avoid persons or places of disreputable character
    - Report to the probation officer (PO) weekly
    - Work faithfully at suitable employment
    - Remain within a specified area
    - Pay all court costs, fines, and restitution debts
    - Participate in community-based rehabilitative programs
  - Intensive: The rules of intensive probation generally entail:[5]
    - A period of reporting to the PO daily
    - Strict curfews
    - Weekly drug testing
    - Mandatory community service
    - Verification of employment
  - Shock Probation**:** Offenders are briefly incarcerated to impress upon them the grimness of prison life and the seriousness of their crime. They are subsequently released into probation.[6]
  - Community-based: A probation system based in privately operated group homes. In addition to supervision similar to standard probation, these halfway houses also offer job placement, substance abuse rehab, counseling, and medical care.[7]
  - House Arrest: An intermediate punishment using the offender's home for mandatory evening and weekend confinement. Travel is severely limited, and offenders must maintain employment, complete community service hours, and make payments to victims.[8,9]

- Electronic Monitoring: Approved for general use in 1984, electronic monitoring utilizes electronic transmittal devices to verify the location of an offender during specified times.[10,11]

- RECIDIVISM: The phenomenon of offenders relapsing into criminal behavior after an initial cycle of arrest, conviction, and punishment.[12]

- RESTITUTION: A court-ordered monetary payment by the offender to the victim for the harm reasonably resulting from the offense.[13]

PHILOSOPHICAL MODELS[14]

- Rehabilitation Model: A philosophical approach to probation and parole that emphasizes community protection via offender treatment and rehabilitation. PO's role is "ego-strengthening" of offenders through identification and relationship.

- Deterrence Model: Approach that aims to reduce crime through the threat of punishment. PO's role is surveillance of offenders.

- Desert Model: Approach that seeks to apply penal sanction for criminal behavior. PO's role is enforcement of terms of release.

- Justice Model: Approach that seeks to apply a just and fair sanction for criminal behavior. PO's role is surveillance and policing activities, advocacy and aid upon request.

SENTENCING MODELS[15,16]

- **Indeterminate**: A judge determines the type and duration of a sentence within statutory bounds and a parole board is given the authority to release offenders.

- **Determinate**: A judge determines a type and fixed duration of sentence for certain crimes. No parole board exists, but inmates may accumulate "good time" credits to accelerate release.

- **Mandatory**: A judge follows statutory law to determine the sentence for certain crimes. "Mandatory minimum" sets the shortest sentence that can be applied in all convictions of a particular crime.

- **Presumptive**: A judge follows statutory law to determine sentencing for all crimes, with higher and lower bounds designated for mitigating circumstances. Sentencing may be determinate or indeterminate, but judges departing from proscribed bounds must provide written justification for appellate review.

INTRODUCTION

The Bureau of Justice and the Federal Bureau of Investigation report that 896,000 aggravated assaults, 40,600 robberies, 8,400 rapes and just over 15000 rapes took place in the year 2000.[17,18]

From 1990 to 1999, the number of violent offenders in Federal prison rose 39.7%, and the number of drug offenders rose 124.4%.[19] By the end of 2000, Federal prisons were operating at 31% above capacity, and State prisons were operating between 100% and 115% of capacity.[20]

Of the 980,000 adults convicted of felonies by state and federal courts, 68% were sentenced to an average of 5 years in prison, but these individuals could expect, on average, to serve less than half this term. The remaining 32% of convicted felons were sentenced directly to probation, with an average sentence of 3.25 years.[21] While just shy of 2 million people were incarcerated in the U.S. at the end of 2000, 4.6 million were on probation or parole.[22]

Parole violators comprised 206,000 of 565,000 State prison admissions in 1998, up 54% since 1990. Among those released from parole supervision, 42% returned to incarceration, and 62% of released state prisoners were rearrested within 3 years.[23]

These stark figures need no introduction. No subtle analysis or statistical manipulation will change the fact that Americans today live in a society where prisons and jails are at the bursting point, crime is pervasive, and criminals are released into society to commit offenses time and time again.

The Innovative Tracking Systems team attempts in this thesis to identify the most alarming trends in the criminal justice system, describes the evolution and interactions of

key problems, examines historical solutions and their ramifications, and proposes a novel solution. Our research culminates in the formation of an executive summary for the business plan of TRX-Systems, a private corporation created to implement a technological solution to identified problems.

HISTORY:

Crime and Punishment Prior to 1800:

Early responses to crime ranged from trial by combat to banishment to death by torture, and tended to converge on the vengeance system of *lex talionis* – an eye for an eye.[24] In 1750 B.C. this violent system of law was recorded and standardized in Hammurabi's Code, yet the same code also set an early precedent for the more 'civilized' practice of forcing criminals to make financial reparations to the victim.[25] The ancient Hebrews also adopted a system of justice modeled on *lex talionis*, but under biblical law punishments were primarily financial. Criminals who were unable to meet their fines were forced into involuntary servitude, which Abandinsky cites as a precursor to the concept of probation.[26] In later years, the Romans infamously and extensively utilized the death penalty, eliminating the use of fines for criminal offenses. As Europe rose from the Dark Ages after the fall of the Empire, fines and restitution gradually became an important form of punishment. Those who were already powerful used this avenue to become wealthy as well.[27] Trial by combat flourished, as did trial by ordeal. In these cases, 'guilty' defendants received verdict and sentence simultaneously. Compurgation, or wager of law, eventually spread through Europe. Under this system, the accused was required to gather twelve citizens who would swear to the defendant's innocence. Over

time, compurgation evolved into the modern concept of trial by jury and sworn testimony, though coerced confessions, torture, and public executions continued throughout the Middle Ages.[28]

For centuries, criminal law as riddled with institutionalized corruption and bias. Crimes committed by the powerful or wealthy resulted in little consequence, while the majority of the population was subject to harsh and final judgment. The advent of the European Enlightenment in general, and the inception of the classical school in particular, would forcefully challenge this state of affairs.

Enlightenment philosophers such as Baron de La Brede et de Montesquieu and Francois-Mari Arouet Voltaire vocally opposed the inhumane and inequitable aspects of the French penal code, while Jean Jacque Rousseau and Cesare Bonesana marchese di Beccaria argued for the radical concept of equality-based justice.[29] A central concept to the classical thinkers was that of the social contract. Rousseau states, "The social contract establishes among the citizens an equality of such character that each binds himself on the same terms as all others, and its thus entitled to enjoy the same rights as all others".[30] That is, in order to be safe, each individual consents to punishment if they resort to crime. Accordingly, punishment is justified because classicists hold offenders to be rational and endowed with free will thus able to make a rational choice – the corresponding legal concept is *mens rea* from the Latin "guilty mind".[31] This school of thought not only provides the underpinnings for the justice and deterrence philosophical models, but also for determinate sentencing.

In opposition to the classical school stands the positive school. Positivism refers to an empirical method of examining and comprehending human social behavior.

Developed by Auguste Comte and Cesare Lombroso, this philosophy places emphasis on the criminal, rather than the crime.[32] It directly contradicts the theory of free will, and posits instead that there exists a deterministic basis for criminal behavior. Positivism attributes a crime to a 'chain of interrelated causes', such as damaging social, economic, and psychological conditions, over which offenders have no control. Under this model, punishment is not justified because offenders are assumed to lack *mens rea*: however since offenders are still potentially dangerous, they must be rehabilitated. It should be noted that, "Retribution and revenge necessarily imply punishment, but it does not necessarily follow that punishment is eliminated under rehabilitative regimes."[33] Positivism underlies both indeterminate sentencing and the rehabilitative model of criminal justice.

Now that we have briefly summarized pertinent sections of the history and philosophy of criminal justice, we may turn our attention to the development of nonincarcerated offender supervision in the Unites States.

Parole and Probation in the United States 1800 – 1900

PAROLE:

The nineteenth century was a dynamic period for the United States legal system. In particular, the concept of parole developed and began to blossom. The word parole is from the French *parol*, referring to the "word of honor" prisoners of war would give not to resume arms if released. The American institution was formed from a combination of pressures. Determinate sentencing in the early 1800s led to overcrowded prisons and widespread institutional problems. Governors frequently granted pardons to large

numbers of inmates to alleviate such crowding.[34] In some states, this power was delegated to prison wardens.[35] These wardens preferentially released well-behaved offenders, a practice formalized by a New York "good time" law in 1817.

American development of parole through the mid 1800s was heavily influenced by European experiments in penology. In particular, American parole was shaped by three major events: the transportation of felons to America for indentured servitude, Maconochie's tenure at Norfolk Island, and Crofton's establishment of the Irish System.[36]

Criminologists commonly accept that punishment by transportation is the principle forerunner of parole. Transportation was an organized, uniform process by which thousands of convicts were punished, though not by execution or corporal punishment and sometimes without a period of incarceration, and through which they eventually obtained their freedom.[37] Furthermore, the modern parole follows a procedure similar to that of indentured servitude. Like the indentured, parolees agree in writing to accept certain conditions regulating behavior and travel; indeed some of those conditions are very similar to those included on indenture agreements.[38]

In 1840, Alexander Maconochie became superintendent of the Australian penal colony on Norfolk Island. Norfolk was notorious for housing the most dangerous felons, and riots were commonplace. However, Maconochie instituted a system of marks to be earned by each inmate for good behavior; the indeterminate sentences carried by his felons could be terminated when a certain amount of marks was reached.[39] Furthermore, Maconochie's system had three stages on the path to release – each successive stage entailed greater personal liberty. The precedent for 'good time' release credits is clear.

The final major event influencing modern parole was the establishment of the Irish System. Sir Walter Crofton became the director of the Irish prison system in 1854. He was familiar with the work of Maconochie, and borrowed elements of his system. Under the Irish System, criminals were rotated through 4 stages of punishment, work, rehabilitation, and release.[40] Again, a system of marks was used to track progress. Under the Irish system, the Inspector of Released Prisoners supervised conditionally released prisoners in Dublin. This official required the offenders to report at stated intervals, verified their employment, and visited their homes every two weeks. He was in essence, the first modern parole officer.

The Irish System was adopted by England, and heavily publicized in America. In 1870, the first meeting of the American Prison Association was held in Cincinnati, where the Irish System received heavy advocacy.[41] By 1876, the Elmira Reformatory was opened, headed by Michigan penologist Zebulon R. Brockway. The Elmira system's motto was clearly based on positivism, as expressed by Brockway's colleague Frederick Wines, "Criminals can be reformed; [it] is the right of the convict and the duty of the state."[42] Elmira followed a classification system very similar to the Irish System. Continued good behavior resulted in conditional release, under which parolees were required to report at regular intervals and account for his situation and conduct.[43] The Elmira system was deemed to be a successful social experiment, and was copied in Massachusetts, Pennsylvania, Michigan, Illinois, Ohio and California before the turn of the century.[44]

PROBATION:

As mentioned earlier, the concept of probation has its roots in ancient Hebrew tradition. A second, more modern incarnation developed from the English practice of judicial reprieve. A reprieve allowed for the temporary suspension of a sentence to allow the defendant to appeal to the Crown for a pardon.[45] Although this was originally intended to be only a temporary postponement of punishment, it rapidly developed into a suspended sentence where no punishment actually occurred. With most of English law, this tradition carried over into American law and has been documented as early as 1830 in Boston courtrooms.[46] Originally, judges simply used 'release on recognizance' or bail and failed to take further action, but by the middle of the nineteenth century, many courts were overtly using judicial reprieve to suspend sentences.

In 1841, John Augustus, a Boston shoemaker, began his work as the nations first probation officer. He wrote in *Report of the Labors of John Augustus*, "I was in court one morning…in which the man was charged with being a common drunkard. He told me that if he could be saved form the house of Correction, he would never again taste intoxicating liquors: I bailed him, by permission of the Court."[47] Encouraged by the experience, Augustus continued his work, taking charges on bail and helping them find work or a residence, and reporting on their progress to the court. He developed several approaches that remain a part of modern probation: working mainly with first offenders, investigating the history and character of each individual, and keeping careful case records. Encouraged by his work, Massachusetts enacted the first probation statute in 1878. Vermont, Rhode Island, Maryland, Illinois, Colorado, and Missouri had each followed suit by 1897.[48]

Parole and Probation in the United States 1900 – 1980:

PAROLE:

In 1907, New York extended parole release to all offenders except those convicted of murder. This marked the beginning of a nationwide trend: by 1922 parole was utilized in 44 states, and by 1939 only three states remained without official parole systems.[49] Four years later, every jurisdiction in the nation had a parole authority.[50]

PROBATION:

Because no statutory authorization existed for suspended sentencing, which was still a common practice near the end of the century, the issue was litigated in 1894 in New York. The court determined that the power to suspend a sentence was inherent in criminal courts only when this right had been granted by the legislature.[51] In the subsequent 1916 Killets Decision, the United State Supreme Court also ruled that judges did not have the discretionary authority to suspend a sentence. In the same decision, the Court further supported the lower court's 1894 ruling by stating that Congress could authorize the temporary or indefinite suspension of a sentence.[52,53] Consequentially, this decision led to the National Probation Act of 1925, which allowed courts to officially suspend a sentence and place an offender on supervised probation.[54] By 1938, 37 states, the District of Columbia, and the federal government had authorized discretionary probation sentences, and by 1956 probation was available for adults in every state.[55]

Parole and probation are unrelated concepts with distinct histories; however, due to the parallels in administration of these services and their similar impact on the prison

population we shall refer to probation and parole collectively as 'nonincarcerative supervision" and refer to them as a single subject for the continuation of this thesis.

Parole and Probation in the United States 1980 – 1990:

The 1980s witnessed a dramatic shift in offender management procedures and goals. Notably, the aim of rehabilitating offenders gave way to a crime control mandate, sentencing of offenders became more formulaic, parole authority was revised, and new corrections techniques came into use. In 1984, Congress passed two precedent-shattering pieces of legislation, the Comprehensive Crime Control Act of 1984, and the Bail Reform Act of 1984. These initiatives changed the face of criminal justice in America. While this section primarily addresses federal legislation, state-level crime management laws tracked the national paradigm shifts in most cases.

The first, the Comprehensive Crime Control Act of 1984, replaced the existing discretionary sentencing system with a determinate one.[56] A subsection of the Crime Control Act, The Sentencing Reform Act, established the United States Sentencing Commission and charged it with establishing federal sentencing rules, advising the government on crime policy, and serving as a clearinghouse for information and analysis regarding sentencing.[57] The Commission's mandate was to create and maintain determinate sentencing guidelines to be used by judges in assigning punishments. These guidelines consider both the severity of the offense and the offender's criminal history. Before this standardization, sentences were indeterminate and left to judges' discretion. This led to the perception that justice was not being fairly meted out, and it was a main

goal of the Sentencing Commission to calm the national outrage with sentencing disparities.[58]

The Sentencing Reform Act also abolished parole for offenders sentenced under its provisions. The intent of this measure was to address the complaint that offenders frequently served only a small fraction of the time they were sentenced to in prison. Although parole was eliminated in name, inmates were credited with "good behavior" sentence reductions of up to 54 days annually.[59] It is generally held that the Comprehensive Crime Control Act resulted in more offenders entering the prison system and offenders serving more time there than ever before. Figures 1 and 2 below support this assumption.

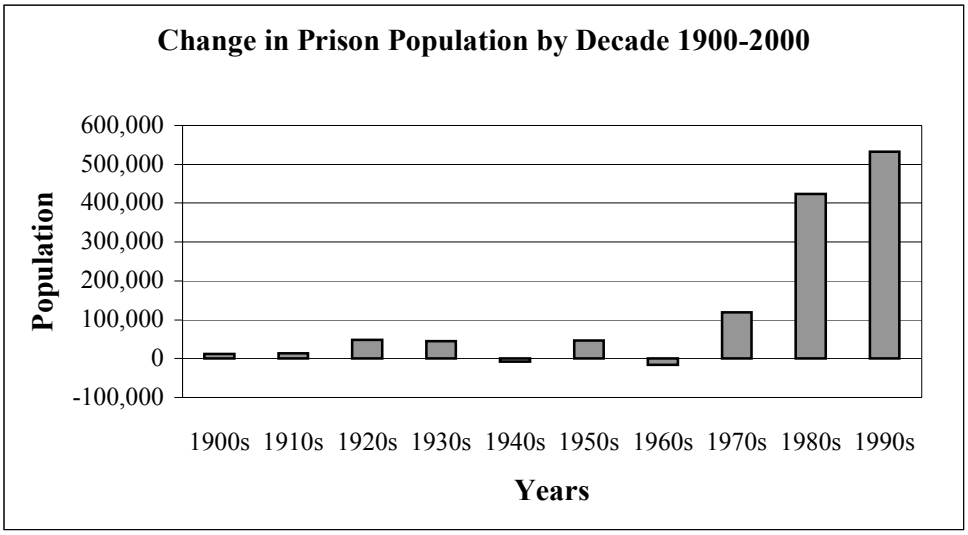


Figure 1: The increase in the prison population in the 1980's was 13 times greater than the average of previous decade gains this century. Source: Justice Policy Institute analysis of US Department of Justice data.[60]

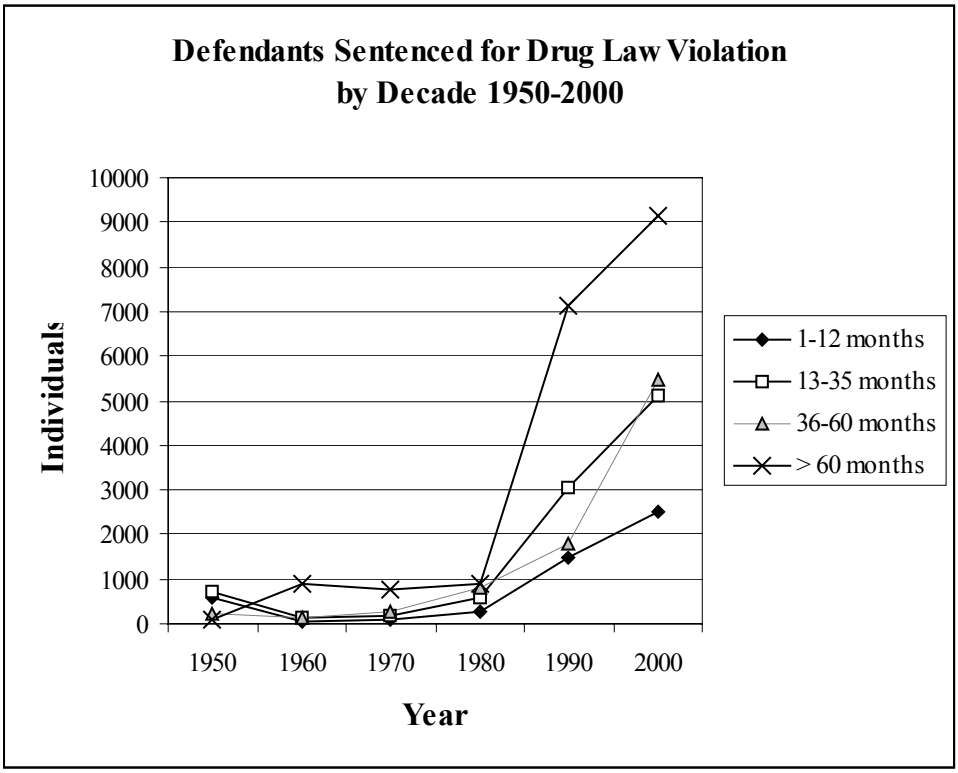


Figure 2: Using drug violations as a representative offense, the 1980s witnessed substantial increases average sentence duration. Source: Sourcebook of Criminal Justice Statistics 2000.[61]

The second major legislation was the Bail Reform Act of 1984, which set standardized procedures for the arrest and release of criminals awaiting trial, sentence, and appeal.[62] The Bail Reform Act established criteria for the discretionary release of prisoners in various situations. Notably, it provided a procedure setting release conditions. Curfews, return to custody for certain hours, and detention at a treatment institution were deemed acceptable conditions, because they "reasonably assure the appearance of the person [at trial] as required and the safety of any other person and the community."[63] Overall, the Act established criteria ensuring fair and equitable pretrial release of the accused while still protecting society from potentially harmful individuals.

Parole and Probation in the United States 1990 – Present:

Recent developments in criminal justice in the United States have again transformed the corrections system and introduced new challenges for policymakers. Notably, "get-tough" initiatives such as three-strikes-and-you're-out laws, truth in sentencing initiatives, and alternative punishment programs are unprecedented in American justice. While solving some short-term problems, many theorists argue that modern sentencing inventions actually recreate problems faced by corrections over the past decades.

A three-strikes program such as that created by the federal Violent Crime Control and Law Enforcement Act of 1994[64] mandates "life imprisonment without release for an offender convicted of a federal offense, if the offender had two prior state or federal court convictions for qualifying offenses."[65] In a similar vein, California's 1994 three-strikes referendum punishes repeat offenders by drastically increasing penalties for second and third offenses.[66] While such penalty structures were instituted to reduce recidivism, it is also possible that increased penalties for a second or third offense may escalate the severity of a recidivist's crimes.

The three-strikes laws reflect a growing public outrage with the perception that criminals are receiving light punishments by an overburdened legal system, with jails serving as no more than a revolving door for offenders. Similarly, citizens complain that a criminal sentenced to a particular sentence is not likely to actually serve the sentence – in other words, that the sentence itself is a farce. Truth in sentencing laws deal with this criticism by requiring that offenders serve at least a specified portion of their sentence. In Michigan, an 85 percent rule was passed after a convicted cop-killer was released after

serving less than half of her sentence, notwithstanding numerous prison rule violations and an escape attempt.[67] Truth in sentencing is the opposite of the "good time" rules with regard to prison terms. Rather than allowing time to be subtracted from prison terms for good behavior, time is added to the sentence for poor behavior. The idea is that offenders are imprisoned for a particular crime, and they can be "rewarded" for good behavior by being released on their scheduled release date, not later.

The net effect of sentencing reforms such as these is that offenders are sent to prison more quickly, and spend more time there before being released. In essence, American criminal justice is returning to the prison overcrowding crises that reforms a decade ago were meant to correct. Many states are currently experimenting with boot camps or other alternative punishments that decrease prison populations and are thought to be more productive methods of reforming offenders. In fact, the 1994 Federal Crime Control Act includes a provision funding state alternative punishment programs.[68] Nonetheless, the efficacy of such programs has not yet been proven. It is likely that the American corrections system will soon see an overcrowding crisis similar to the one it faced ten years ago, and novel solutions are likely the only way to escape this cyclical syndrome of strict punishment and rapid release initiatives.

Modern Functions of Parole and Probation

Throughout modern history, politicians, humanitarians, and taxpayers have waged furious debates over the specific functions and goals of the criminal justice system in general, and parole and probation in particular. Definitions of parole and probation abound; experts have identified the practices as legal dispositions, punishments, administrative

processes, treatment alternatives, or even as measures of leniency.[69] While it is clear that there is no consensus on the singular goal of probation and parole, there are a number of major functions that are commonly agreed upon: crime control, deterrence, punishment, rehabilitation, reintegration, relief of overcrowding, and restitution. While definitions of these functions might be considered vague, and the though the goals of the functions may be contradictory, they provide a useful introduction to the philosophy behind the policy.

Parole and probation are thought to control crime by reducing an offender's opportunities to commit crime through the supervision of their case officer. This concept is heavily applied in intensive supervision programs (ISPs). ISPs employ random officer visits, frequent mandatory check-ins, and tight curfews to limit offenders' opportunities to break the law. And in fact, empirical data seems to validate the practice. According to studies in Georgia, Massachusetts, and New Jersey, ISPs are effective in reducing offender misconduct, particularly when surveillance and control strategies are combined with rehabilitative services, such as drug treatments and support groups.[70] In this same study, researchers from New Jersey found that while ISPs created a more cumbersome administrative system, the programs were still more cost effective than imprisonment and did not increase recidivism.

In a similar vein, probation and parole deter criminals from committing further crime through the threat of reincarceration. ISPs also employ this strategy because close offender supervision results in a higher probability of probation/parole revocation and jail time for new transgressions.[71] It is virtually impossible to isolate the effects of crime control from the effects of deterrence, since both impact actions that have not yet been performed and therefore cannot be measured.

A breakthrough study by Morris and Tonry in 1990 supported the hypothesis of "punishment equivalencies", that is, at some level community-based punishments are as severe as prison terms.[72] While it may appear obvious that remaining in the community is often preferable to being in prison, a Minnesota study revealed that due to the restrictive nature and strict requirements of that state's ISP, many offenders believed that prison was preferable. [73] This study revealed another aspect of probation and parole, that of punishment. Historically, punishment has been a major component of justice, if not considered to be virtually synonymous. Probation and parole constitute punishment via the restriction of behaviors, community service requirements, and financial penalties. Varying combinations of these elements can individually tailor sentences so that the punishment does indeed fit the crime. This study was crucial in reinforcing the role of probation and parole as effective punishments and not merely a "slap on the wrist".

One of the newest forms of probation, community service, seeks to both rehabilitate criminals and reintegrate former inmates into a lawful society. Community service has several important results: it can be applied without direct financial cost to the offender, participants gain personal satisfaction from their work, and it places offenders back into the community in a supervised role.[74] Though case workers and other staff monitor the behavior of offenders while on assignment, it is the sole responsibility of the offender to schedule their hours, show up at assignments, and complete their required time commitment. Thus community service orders can be rehabilitative through holding offenders accountable for their actions and therefore catalyzing the formation of a new sense of accomplishment and ability.[75] Furthermore, if offenders successfully complete

their assigned tasks, they may receive a good reference or employment opportunity, which serves to successfully reintegrate the offender into society.[76]

Another main function of probation, and one of the most practical, is that assigning prisoners to probation or parole eases strain on the nation's incarceration system. While overcrowding is a separate issue that will be discussed in detail later in this text, it is worthwhile to consider that if parole and probation were not options, the current prison population would triple from 1.9 million to 6.4 million incarcerated individuals.[77]

Finally, probation allows prisoners to make financial restitution to both the criminal justice system and victims. This practice dates back to ancient times.[78] Under Mosaic law, thieves were required to repay victims from whom they had stolen oxen. Under Middle Eastern codes, such as the Sumerian Code of Urnammu circa 2050 B.C. and the Code of Eshnunna circa 1700 B.C. most offenses, not just property crimes, required restitution.[79] The Roman law of Twelve Tables circa 449 B.C. elaborated on the concept of restitution by prescribing repayment schedules for theft according to when, and under what circumstances, the thief stole the property.[80] In a Western example, offenders were required to restore peace by repaying the victim and the victim's family for damages in ninth century Britain.[81] The main purpose of such institutionalized restitution was to prevent vigilante justice and retaliatory violence, while providing for a means of reparation. Restitution fell into disuse during the feudal era as royalty began assessing ever-larger fines of offenders. This state of affairs did not change with the rise of the modern states, because this yielded a focus on crime as a disruption of state security rather than as a detriment to the victim.[82] It was only in the 20th century that

criminological philosophers began calling for the re-institution of restitution as a penal sanction.[83]

The major legislative effort to institute restitution in the United States was the Victim and Witness Protection Act of 1982.[84] While that act only allowed the federal government to recover financial damages for victims, restitution in general has three main goals: to financially amend for damage done to citizens, to promote an increased sense of accountability and responsibility leading to reduced offender recidivism [85,86] and to deter offenders from crime by lowering the net financial gain of crime.[87] Restitution payments also help alleviate court, prison, and probation supervision costs. In fact, with correctional costs increasing as the prison population continues to grow, many state governments are opting for making offenders pay for their supervision and rehabilitation. This restitution is in addition to court costs and making prisoners on work release contribute a portion of their earnings to their government agencies. A study conducted in Texas illustrates the potential earnings benefit of restitution. In 1990, Texas spent more than $106 million to supervise probationers, but collected $57 million in fees.[88] Moreover, some of those collected fees were used to expand rehabilitative services for offenders; therefore restitution benefits both the system and victims.

PROBLEMS WITH THE U.S. CRIMINAL JUSTICE SYSTEM

Judicial Overload:

The problem of judicial overload can be simply stated in market terms: demand outweighs supply. There are limited numbers of judges and state prosecution attorneys and the hours each may work per day is naturally constrained. In the past two decades,

the problem of judicial overload has become more pronounced. According to the American Bar Association, since 1984, criminal filings in state courts have increased by 35%, juvenile cases have increased by 59% and domestic relations cases have increased 65%.[89] Most experts correlate this dramatic increase with the "get tough" initiatives of the 1980s as referenced earlier in this paper.[90] Similarly, in recent years, aggressive anti-drug policing has markedly increased total criminal fillings in Federal courts.[91] The increasing caseload on criminal courts is of chief concern both because the Bill of Rights assures a speedy trial for the accused, and because slow processing has a dramatic effect on pre-trial detention costs. Since 1997, the U.S. Federal Judiciary alone reports a 45.5 percent increase in the number of pending criminal cases.[92]

Plea Bargaining

In the middle of the nineteenth century, prosecutors were becoming frustrated by an increasing rate of acquittals. A trend toward avoiding chancy jury trials via the use of plea-bargaining to obtain convictions rapidly intensified, and by 1860 jury trials were already the exception. Plea-bargaining is formally defined by Black's Law Dictionary as, "the process whereby the accused and the prosecutor in a criminal case work out a mutually satisfactory disposition of the case subject to court approval."[93] The defendant will usually plead guilty to a lesser offense or to a lesser number of a multi-count indictment in return for a lighter sentence. Today, more than 90 percent of all cases in criminal courts are disposed of without trial and 80 percent of all felony indictments end in guilty pleas.[94]

Non-trial discretionary justice

It is widely accepted that plea-bargaining has eased the strain of judicial overload, [95] and at first glance plea-bargaining seems to be an effective and efficient practice. Fewer cases go into litigation, judges' time and taxpayers' money are conserved, and prosecutors enjoy the prestige of high conviction rates. However, this miracle cure is not without its share of problems. Debate rages over the validity of plea-bargaining as a legal standby. Scholars have argued for years that the system is inherently flawed and unfair to defendants.[96] Others object to it because criminals generally benefit from bargaining with the state and avoid "appropriate sanction" for their crime. Some argue that state's attorneys are given too much leeway to settle cases outside the court, effectively circumventing a suspect's Constitutional right to a jury trial. The prosecutorial issue at hand here is one form of non-trial discretionary justice.[97] Non-trial discretionary justice issues especially plagues minorities. In increasingly strained judicial systems where time is at a premium and legal advice for the majority of defendants is minimal, plea-bargaining "exaggerates preexisting biases about class, race, and ethnicity."[98]

Discrimination

According to Black's Law Dictionary, discrimination is "the effect of an established practice which confers particular privileges on a class arbitrarily selected from a large number of persons, all of whom stand in the same relation to the privileges granted and between whom and those not favored no reasonable distinction can be found."[99] The laws of the United States forbid discrimination based upon race, ethnicity, gender, religion, nationality, disability, or sexual orientation. Yet black males convicted

today are 7% more likely to be incarcerated than convicted white males.[100] For a murder conviction, a woman's sentence is only 2/3 as long as that of a man, and on average, she will be released on parole 10 months earlier than him.[101]

The United States Justice Department is not blind to disparities in criminal justice and mandates that in order to protect every citizen's "essential right[s], law enforcement agencies should adopt policies that ensure officers perform their duties in a non-discriminatory manner." To this end, the department requires education throughout all law enforcement personnel's careers. There are three components: the first "explain[s] non-discrimination, use of force and other citizen interaction policies"; the second "assess[es] whether the content of these policies has been absorbed."; and the third "[periodically re-assesses whether] the policies continue to be understood by all who implement them."[102] A second initiative promotes diverse bureau staffing to improve an agency's relationship with the community, to enhance trust in the fairness of law enforcement, and to solicit citizen support and cooperation.[103]

Despite the efforts of the Department of Justice and other law enforcement agencies to eradicate prejudice in the legal system, there are still a disproportionately high number of minorities, particularly males, currently incarcerated in the United States. In 1996, the rate of incarceration for African-Americans males was 6,607 persons per 100,000 population. The rate for African-American females was 474 persons per 100,000 population. This compares with the incarceration rates for white males and females, 944 and 73 per 100,000 population.[104] While dissimilar rates of incarceration alone cannot imply discrimination, the fact that the percentage of all African-American

males in prison is an order of magnitude greater than the percentage of all Caucasian males in prison – 8.6% versus 0.9% in 1997 - is a cause for grave concern.[105]

Beginning in the 1970s, the legal system developed its own checks and balances to root out discriminating practices in the system through the creation of internal affairs bureaus. Most major police agencies now have a bureau to investigate complaints against police, which previously had been ignored.[106] To further racial and gender equity, recent years have seen greater appointments and/or elections of many more minorities and women to the bench, prosecutors' offices, and police agencies, especially in top jobs such as police chief and district attorney.[107] This progress led Lawrence W. Sherman, Director of the Fels Center of Government at the University of Pennsylvania to write in July of 2001, "The U.S. criminal justice system is more fair and effective than ever."[108]

Yet the criminal justice system remains far from perfect. Evidence of racial discrimination, violations of citizen rights, corruption, and inefficiency is abundant. Racial profiling, sentencing disparities, and unjustified killings remain major concerns. A 1998 Gallop poll indicated that while 61% of whites have "strong faith" in the police, only 34% of blacks said the same (Sherman). Cincinnati's violent riots in April of last year and the Washington Post's ongoing investigation into police brutality in Prince George's county are two very different reflections of the same thing: public trust in the criminal justice system has failed and the public is vocally demanding a change.

Jail and Prison Overcrowding:

Jail and prison overcrowding is a complicated issue enmeshed in policy and philosophy. A historical perspective clarifies some of the causes and effects leading up to the current burgeoning prison populations. The massive legislative revision in the mid 1980's was preceded by an overhaul of parole board authority. By 1977, 72 percent of all inmate releases were the result of parole board decisions, up from 44 percent in 1940.[109] Although this trend was due to the indeterminate sentencing model of the time rather than lax boards, public outcry resulted in ten states abolishing their parole boards between 1975 and 1982.[110] This initial reduction of parolee releases and the further reduction in releases mandated by the Sentencing Reform Act significantly contributed to prison overcrowding.

As the correction system transformed to meet this new problem, jurisdictions were forced to revamp existing procedures and implement alternative programs to manage the mushrooming offender population. For example, in 1981 Michigan declared a state of emergency due to overcrowding in its prison system. So many offenders were housed in the state's prisons that new arrestees could not be incarcerated. Traditionally, overcrowding was solved by one of three tactics: building of new prisons, enlargement of community corrections, and ad hoc regulation of prisoner intake and release.[111] Michigan's 1981 solution, the Prison Overcrowding Emergency Powers Act, reduced the terms of all prisoners serving minimum sentences by ninety-day increments, and permitted the governor to accelerate parole releases as needed.[112] Although the provisions of the Act were quite novel, legal scholars believe that the process helped to effectively relieve overcrowding while balancing the need for prison beds against public

safety concerns.[113] Other states implemented strict no-growth mandates, restricting the maximum number of prisoners permitted in the system at once: if a judge wanted to sentence one prisoner to jail, another had to be released. Determinate sentencing rules complicated this process in that predetermined sentences were required in cases where it was not possible to implement them.

Through the late 1980's and into the present, the nation has focused on getting 'tough on crime'. Aggressive policing is leading to more arrests while prosecutors are pursuing ever-growing numbers of serious cases. Pretrial detainees, suspects, probation and parole violators, DUI arrests, and persons unable to make bail only add to bursting population figures. At yearend 2000, the total number of prisoners under the jurisdiction of Federal and State adult correctional authorities or in local jails was 1,933,502. This number reflects more than a 300% increase since 1985, as reflected in Figure 3.[114] Prisoners with sentences of more than one year represented 97% of the total State prison population and 86% of the Federal prison population, roughly 1.14 million and 115,000 respectively.[115,116] Overall, the nation's prison population grew 1.3%, resulting in 1 in every 143 U.S. residents being incarcerated. [117]

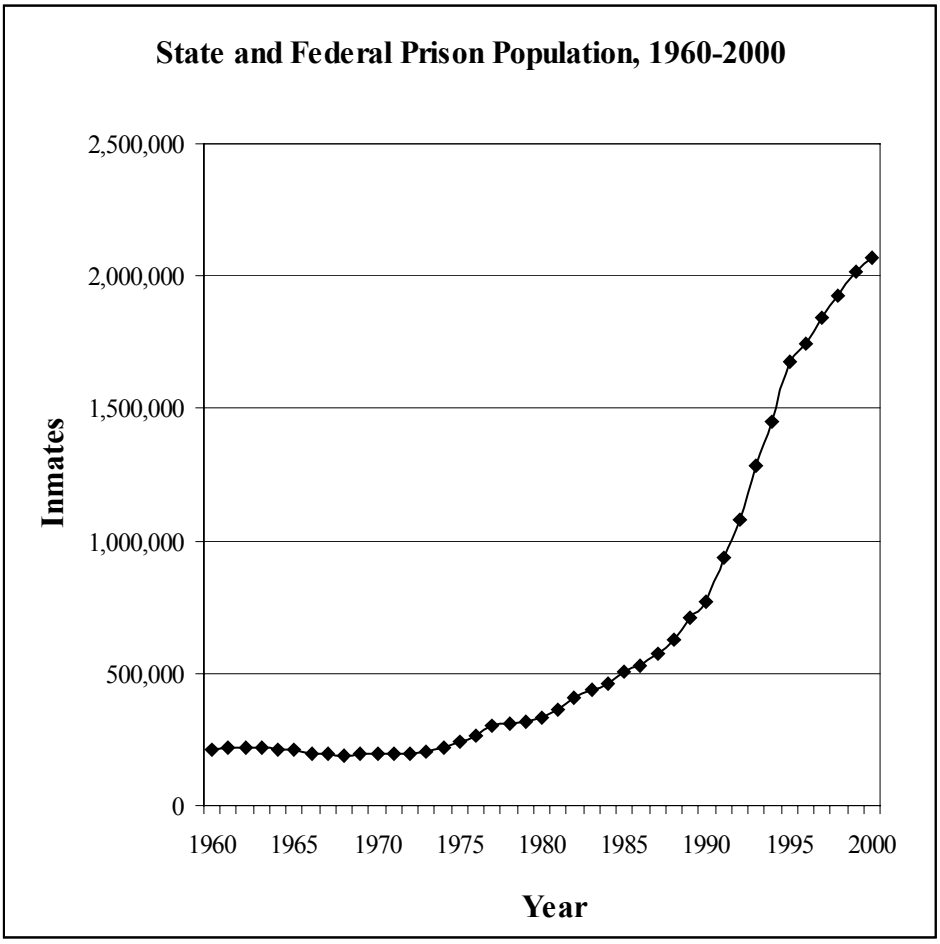


Figure 3: The prison population began a nearly exponential increase beginning in the mid 1980s. Source: US Department of Justice, Bureau of Statistics. Compiled by Jim Thomas.[118]

Prison overcrowding has become one of the nation's most fiercely debated issues. Prison capacity and the extent of overcrowding are difficult to determine because of the absence of uniform measures for defining capacity.[119] To estimate the capacity of their prisoners, jurisdictions give rated, operational, and design capacities. Rated capacity is the number of beds or inmates assigned by a rating official to institutions within the jurisdiction. Operational capacity refers to the number of inmates that can be accommodated, based on a facility's staff, existing programs, and services. Design

capacity is the number of inmates that planners and architects intended for the facility. The Bureau of Justice "Prisoners in 2000" report by Beck and Harrison found that based on the rated, operational, and design capacities, twenty-one states and the federal prison system reported operating at 100% or more of their highest capacity by yearend 2000.[120] Florida reported the lowest percent of capacity occupied, operating at 81% of its capacity, while California reported operating at 94% over its capacity, the worst example of overcrowding.

States' Prison Occupation Rates as a Percent of Ideal Capacity			
State	**Percent of ideal capacity**	**State**	**Percent of ideal capacity**
Federal	131%	**Midwest**	
Northeast		Illinois	161%
Connecticut	...	Indiana	117
Maine	115 %	Iowa	117
Massachusetts	113	Kansas	95
New Hampshire	103	Michigan	97
New Jersey	141	Minnesota	96
New York	127	Missouri	96
Pennsylvania	143	Nebraska	161
Rhode Island	92	North Dakota	97
Vermont	111	Ohio	114
South		South Dakota	97
Alabama	101%	Wisconsin	131
Arkansas	105	**West**	
Delaware	206	Alaska	106%
District of Columbia	83	Arizona	106
Florida	120	California	194
Georgia	90	Colorado	108
Kentucky	99	Hawaii	145
Louisiana	100	Idaho	112
Maryland	99	Montana	175
Mississippi	100	Nevada	117
North Carolina	107	New Mexico	93
Oklahoma	95	Oregon	100
South Carolina	94	Utah	91
Tennessee	97	Washington	158
Texas	98	Wyoming	101
Virginia	91		
West Virginia	98		

Figure 4: Every state maintains populations that meet or exceed ideal capacities. "Ideal" is the lowest rating, design, or operation capacity. Source: Department of Justice, Bureau of Justice Statistics.[121]

At least eighteen major solutions for alleviating prison/jail overcrowding have been proposed.[122] "Front door" solutions like pretrial diversion, shock probation, house arrest, and judicial responsibility measures propose to limit prison intake, while "back door" solutions such as parole, increased good time rewards and furloughs attempt to reduce existing populations.[123] Unfortunately, front door solutions only shift the problems of supervising offenders from the prison system to understaffed, underfunded probation departments in what Kastenmeier calls "a correctional game of musical chairs".[124] Backdoor solutions, on the other hand, increase parole officer caseloads, decreasing supervisory control and increasing recidivism and rearrests, thereby only aggravating the overcrowding they were meant to solve.

In the words of the American Civil Liberties Union's National Prison Project, "[The tripling of the national prison population has yielded] the predictable consequence that facilities are overcrowded; medical systems are overwhelmed; work, education, and treatment programs are inadequate; and idleness and stress lead to greater levels of violence than ever."[125]

Civil Rights Violations and Inmate Violence

Since 1965, lawsuits charging that prison overcrowding constitutes cruel and unusual punishment, and is thus a violation of prisoners' civil rights, have been brought in 47 states and the District of Columbia.[126] Research has indicated that overcrowding has three main effects. First, overcrowding leads not only restricted living space but also a strain on all resources. These may be as inconsequential as library books and television lounge seating or as important as hygiene and medical supplies. Inmates frequently face decreased exercise and washroom availabilities as well. Poor hygiene and poor sanitary

conditions combine with the increased spread of infective diseases to render health care extremely difficult to administer effectively.[127] Secondly, self-improvement and rehabilitative programs, such as academic, employment and vocational training are almost always curtailed. The failure of these programs adversely affects the reintegration of offenders back into society.[128] And finally, a lack of work opportunities may lead to inmate idleness, reinforcing the maxim that idleness breeds discontent and aggression.[129] The success of the plaintiffs in overcrowding suits has been overwhelming: judges have almost unanimously decided against the state.

As indicated above, inmate violence is a secondary result of overcrowding, but one that causes grave concern. In many facilities, violence is endemic. Overcrowding leads to a reduced staff-prisoner ratio, which is likely to mean less effective supervision. Decreased supervision couples with competition and conflict over limited resources to result in unchecked aggression and violence.[130] Crowding creates fear, the inability to maintain personal identity, and the inability to avoid unwanted interaction or stimuli, such as noise.[131] In many cases, inmates cope with these stressors through violence. In 1996, New York alone reported 407 stabbings,[132] but we have little hard data about other forms of victimization. This is due in part because tacit prisoner codes prohibit reporting violence, overburdened staff cannot observe many instances of violence due to time constraints or architectural limitations, and staff also may not be able to detect more subtle forms of victimization.[133]

Psychosis and Mental Illness

It has already been demonstrated that overcrowding adversely impacts prisoners' behavior and access to limited resources. Overcrowding, lack of rehabilitative programs, and idleness further combine to exacerbate mental illness. Because of vulnerability to other inmates, or inability to comply with regulations, mentally ill inmates are frequently housed in protective or punitive segregation, where the isolation leads to further deterioration in their condition. According to the Bureau of Justice statistics, the Nation's prisons and jails housed an estimated 283,800 mentally ill individuals in midyear 1998.[134] These figures are dramatically understated according to the American Association of Community Psychiatrists. They estimate that as many as 400,000 inmates suffer from serious mental illness, not including those who are simply depressed or have anxiety disorders, non-psychotic mood disorders, or impulse control disorders.[135] Unchecked, the number of resulting inmate suicides has blossomed to between 200 and 900% that of the general population.[136,137]

A concomitant of mental illness among prisoners is substance abuse. Recent epidemiological studies cited by the NIDA indicate that between 30 percent and 60 percent of drug abusers have concurrent mental health diagnoses, and that furthermore, these comorbid individuals are exceptionally difficult to both wean from addictive substances and to treat for their mental disorders.[138] With the severe staffing shortages of psychiatrists in prisons nationwide, it comes as no surprise that the majority of these inmates receive little to no treatment or rehabilitation.[139]

Probation / Parole Officer Burnout:

Job burnout has been the focus of multiple debates in the past thirty years. Coined in the human services sector, the term burnout was originally applied to positions with a high turnover rate. In general, job dissatisfaction was viewed as a product of a career producing a "generic state of exhaustion."[140] Burnout was thought to occur because a job was too demanding, leaving workers chronically tired and emotionally overdrawn. This initial assessment was limited by the fact that many jobs without high burnout rates are mentally and physically taxing; therefore, burnout was not simply the result of a demanding career. Researchers such as Jerry Edelwich began noting an important distinction: not only were former employees in the human service areas of corrections unhappy, but they also were disillusioned with the entire social work profession.[141]

As early as 1969, researchers became aware of the effects of 'role conflict'-induced stress in corrections from Daniel Glazer's investigation on how officers obtained their positions. Those who gained employment in probation and parole through patronage or other passive avenues were less likely to exhibit passionate commitment to the work and were unable to act in truly dedicated patterns to the service. This type of officer's dissatisfaction with the profession contrasts markedly with an officer who entered with a burning desire to rehabilitate criminals and to protect the community. Carl Klockars refined Glazer's concept, terming passive officers "time-servers." These employees viewed their job as a position they would until retirement, but never embraced the responsibility or felt they could make a difference on the public at large.[142]

In 1973, Elliot Studt opined that many human service employees in corrections were doomed to the fate of burnout simply because no one person could handle the tasks that were asked of them. Studt identified a "myth of competence," where idealistic young officers from academic criminal justice backgrounds wanted to really 'make a difference' and thought that their studies would useful in actual probation work. The reality of parole and probation work soon altered these officers' attitudes. Studt went on to describe four stages that they normally experienced: naïve idealism, toughening-up, mellowing-out, and finally, disillusionment.[143] Studt felt that disillusionment was relatively rare but that the "mellowing-out," stage was critical because it represented the point at which officers were most likely to become ensnared in the personal lives of their cases. At this point, the employee's job became too emotionally laden, stress peaked and productivity consequentially lagged.[144]

In the late 1970s, Richard McCleary generated new avenues of research and consideration by suggesting that bureaucratic tendencies and administrative neglect were as important as the strenuous process of reintegrating an ex-prisoner into society.[145] Employees were upset that administrations were only concerned with processing cases as rapidly as possible, and that most parolees were reluctant to accept their parole officer as a counselor rather than a warden. The dual pressure of rapid, impersonal case processing and apathetic, frequently defiant offenders rapidly degraded the officers' career confidence.[146]

Maslach Theory

In one of the landmark empirical studies on burnout, Christina Maslach examined "the failure to cope successfully with the chronic stress of client contact."[147] Although

narrowly focus in retrospect, Maslach was the first to identify the three factors that lead to corrections employees abandoning their careers: emotional exhaustion, depersonalization, and lack of personal accomplishment. This research utilized the eponymous Maslach Burnout Inventory to identify the steps officers followed toward their eventual frustration. The second step, depersonalization, was critical in Maslach's studies because at this stage employees no longer viewed their work as a service but as just another case to complete and forget.[148] Eventually, Maslach abandoned the sequential nature of her research and concluded that all three tenets of burnout converged into one overarching symptom.

Cherniss Theory

Unhappy with the limited scope of Maslach's theory, Cary Cherniss proposed two theories of his own, the Limited Model and the Comprehensive Model. The Limited Model was focused on stress as a predictor of burnout and exclusively contained research on new public professionals. Although hardly a widely determinant study, Cherniss concluded that those who entered their profession with the most idealistic goals - those more interested in creating change than financial gain - were most likely to experience severe frustration with the progress of their work. Unsatisfied with this first model, Cherniss soon debuted a more complex model to explain burnout.

Cherniss formally introduced role conflict in 1980, in his examination of the power and normative structures of human services.[149] Officers in corrections are often forced between to choose what they want to do and what are asked to do by their superiors. Cherniss labeled this phenomenon "intersender conflict". It occurs when "an officer [receives] one message to be a counselor and another to be an agent of social

control."[150] Cherniss also believed that the ultimate standardization, uniformity, and efficiency demanded from a public institution is often so constraining that officers cannot approach their job with an individual, humanist perspective much less creativity or novelty. In other words, burnout was a product of a round-peg professional being forced into a square-peg bureaucratic system.

Cherniss was not altogether opposed to uniformity, and in fact, one area of particular strength in preventing burnout was as Whitehead phrases it, "a treatment philosophy that is concrete, accepted, and used… fostering goal clarity and reducing ambiguity."[151] Another preventive measure Cherniss advocates is for supervisors to "champion" their officers. This approach is intended to buffer the morale of officers who constantly interact with difficult cases and deal with the brunt of society's ills. By supporting their employee's interests and publicizing achievements and progress, these supervisors bolster job satisfaction and employees' sense of accomplishment.[152]

Why burnout is problematic

Even with the relative modernization of parole and probationer monitoring, burnout remains an important issue because the shift to computerized processing of caseloads, while it did improve record keeping, only substituted conventional paperwork with digital paperwork. Computerization improves organization and efficiency, but it did not address the fundamental problems of officer overload, ambiguous goals, and unsatisfactory counseling opportunities. Novel applications of technology may in fact, be the key to accurate reporting of required data, improved assessment of offenders' adherence to parole conditions, and reduced caseloads and thus increasing time for counseling. Society's investment in the criminal justice system is much too great to allow working

conditions to demoralize those most devoted to rehabilitation and the reintegration of individuals into the community.

Recidivism:

In the most recent statistics available, individuals in State prisons reported committing 13,200 murders, 12,900 rapes and sexual assaults, 19,200 assaults, and 79,100 robberies and burglaries while they had previously been released under nonincarcerative supervision.[153] In 1997, fully 53 percent of State prisoners who expected to be released by the year 2000 had been on parole or probation at the time of the offense for which they were incarcerated.[154] Also in 1997, over 42 percent of parole violators reported having been incarcerated at least three times in the past.[155] In 2000, the Bureau of Justice reported that only 43 percent of parolees and 60 percent of probationers successfully completed their supervised release programs. It could not be more clear that recidivism is constitutes one of the most glaring problems with today's criminal justice system, thus it is important to examine the concept of recidivism and methods of minimizing its occurrence among probationers and parolees.

There are several notions of what exactly constitutes recidivism. These include: violation of the terms of release, suspension or revocation of conditional release, arrest for a new offense, conviction for a new offense, reincarceration, absconding, or a general reversion to criminal behavior.[156] While each concept has value, none is sufficient on its own to determine the effectiveness of nonincarcerative supervision. Rearrest is a popular indicator of recidivism, but its accuracy is technically debatable, since arrest does not necessarily imply guilt or lead to incarceration.[157] Similarly, an offender may commit a

new crime or violate the terms of their release without being arrested. Probation revocation is a weak indicator of recidivism since it is applied unevenly and may be caused by a technical rule violation and not a new crime.[158] There is no evidence that offenders who violate technical terms of probation are more likely to commit new criminal offenses.[159] With so many possible definitions of recidivism, rates vary greatly from study to study, making it difficult to evaluate methods or form cohesive policies. An additional complication arises because one must also consider the length of time between the release of the offender from incarceration or a probation program and a new criminal offense. This determines whether an offense is considered recidivism or simply a new crime.[160] Champion suggests, and we accept for our purposes, that "reconviction for a felony within the period of one's probation . . . is the most direct measure of program's success or failure" and hence, the most reliable and meaningful indicator of recidivism.

While defining and assessing recidivism as a measure of a specific program's success is a complicated matter, the heart of the issue is a concern for the safety of the public. Recidivism from probation or parole programs endangers the community and therefore must be minimized. Distressingly, the criminal justice system is far from successful in keeping previous offenders from committing new crimes. In 1999, a total of 244,700 probationers and 173,800 parolees were reincarcerated for new offenses.[161, 162] Those numbers respectively comprise 15 and 42 percent of all parolees and probationers released that year. Another 180,000 offenders absconded, adding unknown numbers of crimes to the picture.[163] While the pure magnitude of the problem is staggering, the intensification of the problem in recent years is of particular concern. In 1979, about 41

percent of offenders entering state prisons in 1979 were on probation, parole, or some type of conditional release, but in 1999 *parole violators alone* constituted 35 percent of admissions to state prisons. [164,165]

Perhaps the most frustrating aspect of this problem is that we cannot predict which individuals are most likely to relapse into crime. Generally accepted predictors of recidivism include criminal history, substance abuse, criminal companions, lack of education, poor employment history, and demographics.[166] Correctional staff use advanced statistical techniques such as multiple logistic regression, the Burgess method, and iterative processes to analyze these indicators, but no method has proven to be particularly successful.[167]

Beyond the actual danger imposed by recidivists, it is important to recognize the importance of public perception of that threat. Recidivism drives the public perception of the effectiveness of the criminal justice system, and as a result, public support of rehabilitation programs and supervisory personnel has plummeted, though there is little hard evidence to support this finger-pointing.[168,169] In fact, Petersilia and Turner found that offenders on probation who were enrolled in rehabilitative services, such as anger management and substance abuse programs, had significantly lower recidivism rates.[170] Despite this evidence, the focus of nonincarcerative supervision has shifted from rehabilitation to crime control as a result of public pressure.[171]

However bleak the situation may seem, there are promising developments. Recent research indicates that electronic monitoring improves crime prevention efforts. Since 1983, Florida has used an intensive supervision system utilizing house arrest and 24- hour electronic monitoring.[172] Baird and Wagner conducted a study on this system

and found that after 18 months, offenders under this system had a 20% reduction in recidivism as compared to their peers.[173] As they state, "There is no question that the big-brother level of supervision works".[174] This study shows promising results for the use of intensive supervision and electronic monitoring of offenders.

CONCLUSION

The US currently commits roughly 20 billion dollars[175] to the criminal justice system each year, employing about 2 million police, judges, legal counsels and corrections officers[176], supervising nearly 4.5 million parolees and probationers[177], and housing an additional 1 million inmates.[178] When assessing the tangled web of issues surrounding a system this large it is important to separate problems in solvable categories. No technology can ever address bias and discrimination, but it is possible to use technology to address the problems of overload, recidivism, and burnout. As shown throughout the previous sections, for years attempts to 'fix the system' have merely shifted blame and responsibility to other departments within the justice organization. These solutions have been generally unsuccessful in responding to existing problems and, in many cases, have led to the creation of new dilemmas. Clearly, now is the time for a novel approach.

OUR SOLUTION, THE SENTINEL LOCATION SYSTEM:

Technology Overview

The Innovative Tracking Systems team has engineered a novel two-part location tracking and monitoring system as the founding technology of their start-up business, TRX Systems. Use of TRX's Sentinel Location and Location Management Systems will provide parole and probation officers with highly accurate data to assess the compliance of an individual with the terms of his or her release. These systems are based on three core technologies:

- GPS Location Systems: Satellite Global Positioning Systems (GPS) provide time-location stamps.
- Wearable Computing Technology: Small, high performance, power-efficient processors receive and process location and sensor data, and format alarm and alert messages based on pre-programmed conditions.
- Wireless Communications: Short and long-range wireless technologies transmit location and location-dependent sensor data.

Regardless of the specifics of our technology, we propose herein a variation on electronic monitoring (EM), and thus a brief history is in order. Robert Schwitzgebel, a Harvard psychologist, developed the first monitoring device in the mid 1960s, but it was more than a decade before electronic monitoring was explored intensively as a complement to the parole system in the United States. A 1977 cartoon in which a villain attached an electronic bracelet to Spiderman to keep tabs on his whereabouts piqued the interest of Judge Jack Love of Albuquerque, New Mexico.[179] Six years later Judge Love

imposed the first American house arrest sentence to utilize an electronic monitoring device.[180] Within ten years, the United States had commenced its first federal contract for an electronic monitoring system.[181] In 1998, the District of New Jersey became the first in the country to make use of GPS, and just recently the New Jersey district court determined that a defendant had violated a condition of release solely on the basis of GPS - another first.[182]

In the subsequent years public acceptance of EM has been warm but cautious. At the present time, there are only approximately 95,000 people under the wide umbrella of corrections-based electronic monitoring.[183] Part of the slow deployment of the technology rests in the highly sensationalized nature of system failures. In 1998, both 60 Minutes and 20/20 ran stories on rare examples of electronic monitoring failing to prevent heinous crimes.[184] The American Probation and Parole Association widely endorses the use of electronic monitoring products and quickly defended such systems when in 1997 a lawsuit was filed against the California Youth Authority and BI Inc. because a monitored offender committed murder.[185] In 1998, the APPA made the following statement:

> "An electronic monitoring program implemented in a northeastern state in the early 1990s reported a re-arrest rate for participants of less than two percent; failure rates for non-electronically monitored criminals were 10 times higher… [C]itizens are safer with properly administered electronic monitoring programs than without."[186]

The following sections will consist of a general overview of the conceptual framework, technology, and basic goals of the TRX tracking system. A description of product and system capabilities is followed by operational procedure, a cost/benefit analysis, a competitive analysis, and finally an examination of how the proposed

technology addresses the primary problems of the criminal justice system we identified in the previous section. Please reference appendix 1 for the executive summary of our business plan, appendix 2 for a complete product description, appendix 3 for a summary of GPS function, capability, and limitations, and appendix 4 for pertinent materials engineering design decision information.

Product Description

Tracking and recording unit – The Sentinel Location System (SLS)

The SLS fits a wearable electronic location-recording device to probationers and parolees. Data is recorded to a compact flash memory card so that any time, this information can be downloaded to a supervising officer's computer and reviewed. The Sentinel is designed to resist tampering as well as substantial daily wear-and-tear. If the system the wearer attempts to remove the SLS, an alarm is transmitted. Several optional features enhance the system by tailoring it to the needs of each jurisdiction:

- The device may be configured to allow remote data download for routine or spot checks.
- The device may be preprogrammed with restricted geographic regions for each offender so that:
    - An audible alarm sounds when the probationer enters a restricted region

    - And/or -

    - A wireless alarm transmits the probationer's location and name to the local 911 call center when the offender enters a restricted region.

- The device may be fitted to record and transmit additional location-dependent sensor data. For example, audio may be recorded when a probationer enters a known drug market.

Interactive mapping software suite – The Location Manager System (LMS)

The current low-tech methods of tracking and recording the activities of individuals on probation and parole are time-consuming and work-intensive. The LMS greatly simplifies the probation check-in process by providing a user-friendly electronic alternative to the paperwork most jurisdictions use. It provides a PC software suite that:

- Retrieves data from the SLS
- Records resulting time/location information in a centralized database
- Produces activity reports and infraction logs
- Overlays location history onto the pertinent local maps for rapid and effective officer assessment.

Configuration, Architecture, and Operation

Sentinel Location System:

CORE CONFIGURATION

The SLS consists of the following core elements, securely packaged in a weatherproof bracelet:

- GPS receiver with internal antennae for computation of position using the GPS satellite system

- Non-volatile memories, such as CompactFlash or SmartMedia, will be the medium used to record sensor information on the system. Technology advancements in building smaller, cheaper, and more power-efficient small-form factor memories will dictate the particular storage medium used in the system.
- Base station computer interface allows data to be transferred from the portable storage module to the personal computer with no additional user intervention.
- Battery power pack and charger.

ENHANCED CONFIGURATION

The Sentinel System is upgradeable to provide additional functionality by including the following enhancements:

- Hardened case makes the Sentinel difficult to remove and tamper-resistant, so an offender would have extreme difficulty in removing the system in a short period of time.
- If, for some reason, the device is removed, an internal security system notifies enforcement of the violation.
- Internal security system locks/unlocks the module from the inside when it is properly triggered to do so. If the system is improperly removed, it will be detected by the system's circuitry. In such an event, the internal security system triggers an embedded alarm, records the time and location of the removal event, and then transmitted this information wirelessly to a control center.
- Additional sensors can be added to the device to measure information about the system. Such additional sensors may include accelerometers (to measure

acceleration), gyroscopes (to measure rotation), or audio sensors (to measure sound).

- Alarm onboard the device will sound loud alerts when triggered. The alarm can be triggered from onboard the device, or via a wireless command signal from a remote site.
- Cellular communication platform for transmission of data and reception of command signals. The cellular transmitter automatically calls selected numbers if certain conditions occur.
- The cellular transmitter can send geographic location and other tracked information to a call center by calling set phone numbers. Transmission events can be customized to occur under the following conditions:
    - System is programmed to transmit information automatically at set time intervals.
    - System is receives a wireless command signal to transmit information, such for a spot check.
    - GPS sensor detects the system has entered a prohibited geographic region.
    - Additional sensors onboard the system detect signals that meet preset conditions.
    - The cellular transmitter can place a 911 emergency call and send location, identity, and related sensor values to the 911 call center.
- Short-range wireless transmitter/receiver for transmission of data and reception of command signals.

- The transmitter sends data to a receiver in range. The data includes identity, current location, speed, etc. This option is used when the cellular option is not available (i.e. when no cellular coverage within range), or as a complement to the cellular option.
- The transceiver receives command signals that cause Sentinel data to be transmitted.

ARCHITECTURE

The SLS is an entirely enclosed system, packaged in a weatherproof bracelet, as seen below.

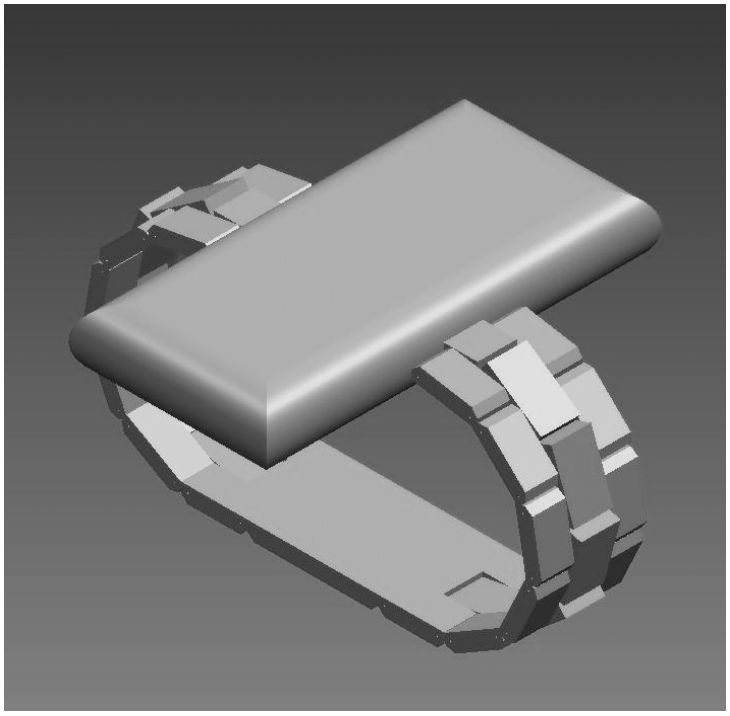


Figure 5: The final design for the SLS wristband unit.

A schematic diagram of the components of the SLS is shown below.

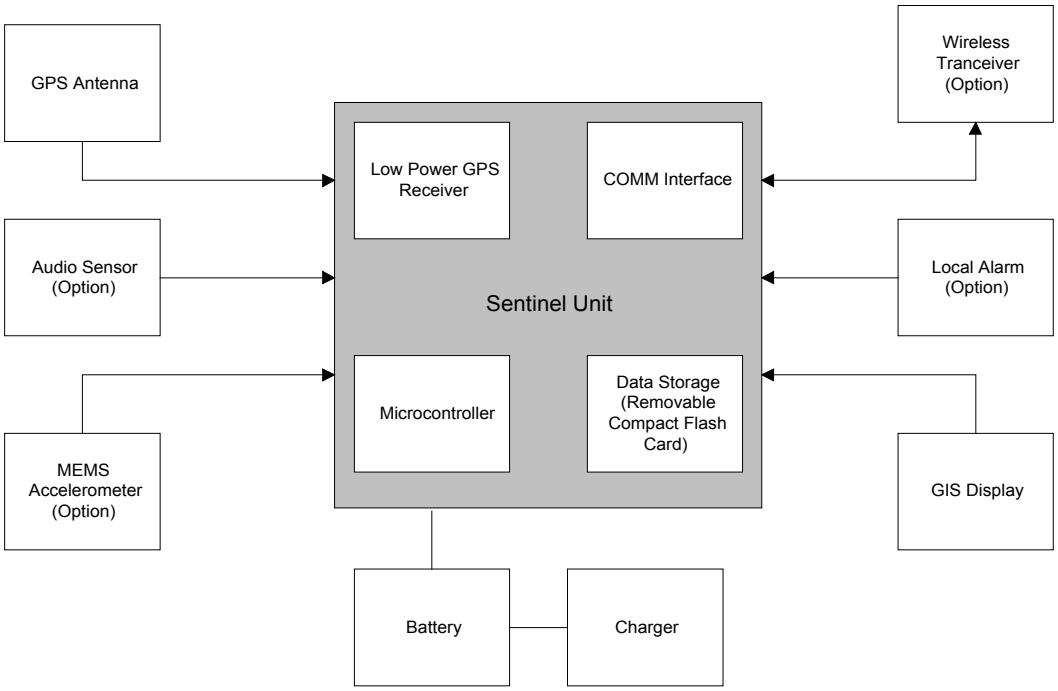


Figure 6: Schematic diagramming the conceptual arrangement of SLS unit components.

OPERATION

Standard operation of the Sentinel Location System is as follows:

- At the police station, the SLS is attached to an offender.
- The internal security system of the SLS is activated, locking the system. The SLS cannot be deactivated without destroying the unit.
- The offender leaves the station and returns to daily life while the SLS records location data at time-varying sampling rates. If the individual is stationary, the unit records the last location and enters sleep mode until movement resumes. If the individual enters a restricted region, the unit records at an elevated sampling rate.
- The probationer returns to the police station for a routine report. The officer unlocks the SLS by sending a wireless command to the SLS internal security

system. The officer removes the memory card from the device, and plugs it to into a memory card reader to be downloaded to a computer.

- The officer reviews the probationer's activity over the past week by using the Location Manager System**.**

ADVANTAGES

- Extended Battery Life: Version one prototype of the SLS provides over a week of continuous operation by battery power; however the proof-of-concept (PoC) prototype developed as part of this thesis consumes significantly more power than the actual system that will be used in law enforcement. The actual system will be manufactured entirely using Application Specific Integrated Circuit (ASIC) and Micro Electro Mechanical System (MEMs) components. ASIC and MEMs are much more power-efficient than the basic electronic components used in the PoC prototype. Battery life is extended via the use of:
  - **Low power devices**. Electronic sensors and controllers used in the system are selected for their low-power consumption and available power-saving modes.
  - **Efficient power management**. The system powers down unused components until the desired function is required. Initially, the SLS receives position data at intervals of 90 seconds. After the data is read and written to the onboard compact flash memory, the entire unit is put in a sleep state for 90 seconds. If the speed of the unit is greater than a specified threshold, the unit will be set to read data every 30 seconds.

Device	Operating Voltage (V)	Current (mA)	Time Active	Power (mW)
Microchip PIC 16F877 (4MHz)	5	0.6	1	3
Motorola M12 Oncore GPS (Active)	5	75	0.05	18.75
Motorola M12 Oncore GPS (Stand-by)	5	0.000005	0.95	0.00002375
Oncore Active GPS Antenna (Active)	5	20	0.05	5
Oncore Active GPS Antenna (Inactive)	0	0	0.95	0
ADXL202 Accelerometer	5	0.6	1	3
32 MB CompactFlash (Active)	5	20	0.05	5
	Total Average Current =	6.35	**Total Power =**	31.75

Capacity of Motorola LI103450E Lithium Battery= 1400 mAh
Total on-time for tracking system = 220.4 hours (about 8 days)

Figure 7: Power consumption of the Sentinel Locator System prototype[187],[188],[189]

- Small Size: The system must be small enough to be comfortably strapped to a person's wrist or ankle. Version one prototype of the Sentinel Locator System is 70 x 70 x 50mm. Again, the proof-of-concept prototype is significantly larger than the system that will be used in law enforcement. Not only are ASIC and MEMs components more efficient, but they are also much smaller than the components used in the prototype. Size estimation of the prototype serves as the worst-case size of the product.
- Expandable and non-volatile memory: Simply substituting a higher capacity memory card expands the memory capacity of the unit. No additional configuration of the new memory card is necessary. In addition, the logged data will be saved onto non-volatile memory in the system, so information is not lost in the case of disruption of the power source.

Location Manager System

CORE CONFIGURATION

The Location Manager System (LMS) is a software suite designed for the dual purpose of managing the Sentinel Location System (SLS) and visualizing the data gathered by the SLS in an easy-to-comprehend format. It consists of two complementary parts:

LMS Manager

- Allows the flashcard to be unlocked from the device and thereby removed.
- Downloads data from the flashcard and prepares it for reinsertion to the SLS.
- Allows for the configuration of the SLS bracelet.

LMS Visualizer

- Based on the Geographical Information Systems (GIS) model, allows for rapid and simple visualization of data gathered from SLS bracelet.
- Loads data retrieved from the SLS via LMS Manager and plots the data on customizable maps.
- Allows standard GIS-style controls such as panning and zooming.

ENHANCED CONFIGURATION

Beyond the basic functionalities outlined above, the Location Manager System provides the following functionality enrichments:

LMS Manager

- Enhances security via a password protection scheme which forbids flashcard removal without proper authority.

LMS Visualizer

- Allows uploading of custom maps for each individual.
- Facilitates multiple layers of mapping. Physical landscape features, political features, and satellite photography, among others can be hidden or displayed at will.
- Interpolates data points retrieved from the SLS bracelet to estimate where the individual was at any given time.
- Allows simultaneous presentation of multiple offender data sets for one time period. Also allow simultaneous display of multiple time period data sets for one offender.
- Automatically highlights areas of multiple data set intersection for quick notification of the user.

ARCHITECTURE

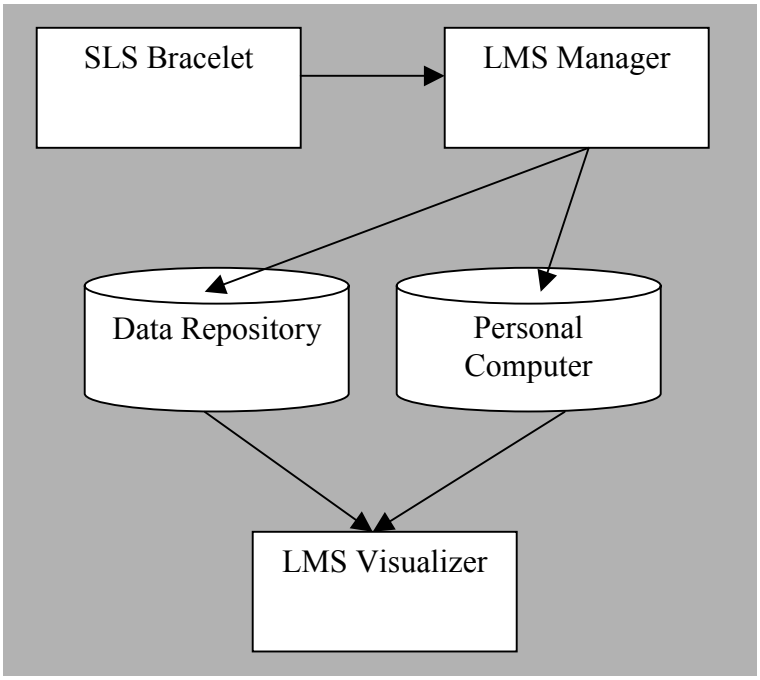


Figure 8: A schematic representation of the flow of data through the SLS/LMS system on its way to examination by the parole agency.

OPERATION

The operation of the Location Manager System can be different for each user, but it adheres to the following generalities:

- Before first use, the LMS Manager is used to remove the flashcard from the SLS bracelet and configure the device.
- Before first use, the LMS Visualizer is loaded with custom maps bought or created by the parole agency.
- When the offender returns for periodic meeting the flashcard is removed and data is downloaded from the disk to the officer's computer or a central data repository.
- Existing data is erased to make room for the next week's information.
- The flashcard is replaced in the SLS bracelet, and the bracelet is reattached to the parolee.
- The LMS Visualizer loads the desired maps and overlays them with downloaded data from the SLS bracelet.
- Using LMS Visualizer, the officer examines the locations the parolee visited for any parole violations.
- Potentially interesting areas of data can be examined more closely by zooming, loading additional data sets, and viewing additional map layers.

COST ANALYSIS

Product Cost

Version one prototype of the SLS has an estimated construction cost of $171.11 based on the individual cost of each of the components of the core system configuration, as illustrated in the table below. The proof-of-concept prototype cost significantly more because the final system will be mass-produced using integrated components, which is much cheaper than individual component purchase.

DEVICE	BULK PURCHASE PRICE
Microchip PIC16F877 microcontroller unit (4MHz)	$8.25 [190]
Garmin GPS Receiver with antennae	$49.87 [191]
32 MB CompactFlash	$19.00 [192]
Dupont Aracon Packaging	$34.00 [193]
Motorola LI103450E Lithium Battery	$59.99 [194]
Total cost	$171.11

Figure 9: Cost breakdown of one Sentinel Location System prototype

Cost Comparison:

While methods of calculating costs varied widely, states reported paying anything between $8,000 and $37,800 per individual for one year's worth of prison incarceration in 1996.[195] According to interviews with state and federal officials, standard probation or parole for one year cost between $800 and $2820, while intensive supervision cost as much as $6000 per offender per year.[196] The practice of assessing 'user fees' to offset the cost of nonincarcerative supervision programs dates back to initiatives in Michigan and Colorado in the 1930's.[197] In 1986, Texas reported fee-generated revenues of $25.8 million dollars.[198] Spurred on by these results, at least 28 states were actively charging supervision fees by 1990.[199] Currently, California charges offenders under home arrest

$4745 per year in fees.[200] Intensive supervision rates seem to converge on $1500 per year, while standard supervision fees amount to about $30 per month.[201,202,203,204] The anticipated price of one SLS unit is $171.11, which is significantly lower than the annual cost of incarceration or of supervision services. The cost of GPS tracking is dropping dramatically, too. In 1998, the cost of tracking one offender with GPS was roughly $40 per day. Today that cost has fallen to between $8 and $12 per day.[205]

Because courts currently testing EM solutions have set legal precedent by ordering offenders to pay for the use of GPS[206], it is quite feasible to add the cost of the SLS to the offender's annual fees. These additions would represent a reasonable increase of only 50 cents per day per offender. For a more detailed analysis of the target market and our revenue model, please see appendix 1.

COMPETITIVE ANALYSIS

Historically, technical improvements to parole and probation have been hobbled by fundamental inefficiencies. For example, traditional home-monitoring systems can only determine if an individual is in his/her home or not. In July of 2000, BI Incorporated introduced a GPS-based location system capable of tracking individuals inside and outside of the home.[207] SkyGuard500 is comprised of four components: an ankle bracelet, a mobile receiver, a base station in the offender's home, and a central monitoring system. While this represented a great advancement, SkyGuard500 has a limited battery life of 16 hours and requires that the parolee wear an anklet bracelet along with an over-the-shoulder pack. Despite the inefficiency and inconveniency of this approach, BI Inc. holds roughly 70% of the US electronic monitoring market.[208] Another

main player, Pro Tech Monitoring, Inc., produces a product called "Smart®". "Smart®" is a GPS tracking system comprised of a 4 pound handheld unit the size of a lunchbox and a bracelet that communicates with the unit. The target may either carry the unit by the handle or wear is as a waist pack. Authorities are contacted if the target loses contact with the unit or violates various rules. The battery lasts from 15 – 30 hours with a 6-hour charge.[209] This pattern of poor battery life hindering a system's ability to perform robustly in a real-life situation is repeated time and again in the electronic monitoring sector. By providing over a week of continuous operation by battery power, the SLS minimizes complications relating to recharging, system downtime, and offender responsibility.

COMPETITIVE ADVANTAGE

As indicated, products on the market currently have a number of fundamental insufficiencies of product design. The Sentinel Location System remedies ungainly unit size, poor battery life, system and source analysis problems, and inferior tamper-resistant designs.

No currently available products combine all pieces of the wearable unit into one compact package. Most have an additional "power pack" that must be worn on the back or carried like a purse. While these separate battery packs are required just to power other systems for one day, the SLS contains enough power for over a week, which also minimizes user responsibility for continued system operation. In other systems, GPS location units tend to be bulky and conspicuous. The miniaturization of the SLS makes our small unit barely visible when attached to an ankle and worn under dress slacks. This

improves offender's quality of life and reduces the stigma associated with what amounts to the modern version of a scarlet A.

The primary design decision facilitating these improvements was elimination of continuous real-time data transmission. As noted earlier, the system can be configured to immediately transmit an alarm to a 911 call center if an individual enters a restricted zone, thus the SLS can prevent crimes before they occur just as effectively as other systems. There is little immediate need for continuous transmission of location data when the target is within approved boundaries, so this information is appropriately stored for later review by a supervising officer.

The system analysis performed by the Location Manager System is also superior to that performed by any system on the market. The LMS uses intelligent path analysis to monitor tracking data. This facilitates the system's ability to make reasonable decisions, without human facilitation, about the target's behavior. When combined with multiple data sources, such as acceleration or motion sensors, trends can be analyzed and effectively managed. A potential application might include monitoring whether individuals with suspended licenses are driving.

Finally, the SLS has a tamper resistant design so that unit would be extreme difficult to remove in a short period of time. If the device is removed, a record is made and officials are duly notified. This design element eliminates the ability of the target to temporarily disable the SLS to 'fool the system', and maintains a longer unit lifespan by deterring attempts to damage or disable the device.

HOW THE SENTINEL LOCATION SYSTEM ADDRESSES PROBLEMS WITH THE U.S. CRIMINAL JUSTICE SYSTEM:

Prison Overcrowding

As demonstrated earlier, overcrowded prisons lead to everything from increased inmate violence to civil rights violations to the failure of prison programs. In recent studies, offender recidivism has also been linked to overcrowded prisons.[210] By allowing judicial officials to more confidently place offenders on probation or parole, the Sentinel Location System will reduce prison populations, which would theoretically result in improved prison conditions, better inmate rehabilitation, and decreased recidivism.

In addition to indirectly reducing recidivism, SLS will actively function as a crime deterrent because offenders will know that their location is recorded at all times. Rational individuals are unlikely to commit crimes for which they may be irrefutably implicated. As Anderson reports, "Most offenders found the idea of an electronic sensor controlled by a computer far more intimidating than a mere human being" (42). Lower crime rates will yield lower arrest rates, and reduce the influx into prisons. For those who are not deterred, at least the SLS can aid officers in identifying and arresting recidivists after the first incident. [211]

Reducing Recidivism

One of the primary purposes of parole and probation is to minimize the loss of social skills that often accompanies prolonged confinement. Theoretically, parole and probation allow convicts to safely serve a large portion of their sentences in a community, which facilitates a smooth reintegration into society. The small size and inconspicuousness of the SLS ensures that while offenders are still rigorously supervised,

their criminal status is not advertised to casual observers. This minimizes ostracism and encourages parolees and probationers to 'start fresh'.

Obviously, reintegration can only occur when parole or probation is successful. In most jurisdictions today, parolees are only loosely monitored and the temptation to break the conditions of their release is strong. When parolees and probationers are being deceptive and constantly trying to evade their supervising officers they are accomplishing the opposite of reformation and reintegration. Requiring each parolee to wear a tracking device would virtually guarantee detection of infractions and eliminate offender's matter-of-fact disregard for rules and boundaries. Convicts would be forced to respect the conditions of their parole or probation, improving the possibility of reintegration via a truly controlled environment.

Improving Reintegration:

Closely related to reintegration issues is the problem of recidivism. The life of a prisoner is controlled entirely by the prison staff, and prisoners often forget how to care for themselves and how to function with the rest of society. This is not necessarily a result of poor prison conditions, because as Martinson observes, attempts to simply improve the prison environment have not reduced the reconviction rate.[212] He hypothesizes that recidivism is a function of the interruption of a normal life in society that comes with the institutionalization process.[213] Upon release ex-prisoners often cannot find legitimate ways of sustaining themselves financially or socially, and return to the easy cash and familiar framework of crime.[214]

Case studies show that electronic monitoring devices are indeed effective in reducing recidivism rates. In 2001, Florida has only had two new felonies committed by 778 electronically monitored violent and sex offenders.[215] A 1998 focused on offenders in Virginia who served sentences in jail, work release centers, and on electronic monitoring. The results of the study showed that "the longer an individual served on electronic monitorin***g***, the smaller the likelihood of rearrest and the longer the time until rearrest."[216]

Ameliorating Officer Burnout:

Parole and probation officers generally spend only a few minutes per week in face-to-face situations with a given offender. Yet one in every four supervisory officers reports spending significant periods of time commuting between the homes and workplaces of offenders to monitor compliance with approved schedules.[217] Improved monitoring and better counseling seem impossible without greatly increasing the number of officers at exorbitant expense. Automating the process of tracking and monitoring parolees has the potential to save enormous amounts of money and time. It additionally frees officers to greatly increase the amount of support and rehabilitative assistance they can offer.

A second major obstacle SLS can help officers overcome is the distrust role conflict engenders. An officer's duty to constantly keep tabs on his charges generally prevents a cordial and trustful relationship from developing between the two.[218] Because parolees and probationers will lie about their activities, officers remain suspicious and distrustful of them. If monitoring were done by machine rather than in person, an officer

and an offender would be able to enter into a more trusting relationship, since behavior would be independently verified. Because unsavory task of policing the parole boundaries would be relegated to the machine, individuals would be more apt to view the officer as a source of assistance rather than as a watchdog, thus the officer would be allowed more intimate involvement in the process of their rehabilitation.

Grappling with Injustice

While the parole and probation system is charged with protecting the public from dangerous criminals, they must also respect the human and Constitutional rights of individuals in their care. While the offenders must be treated firmly in the event of a breach of release conditions, they must also be treated fairly. Advocacy groups complain that offenders are completely vulnerable to false accusations of wrongdoing and discriminatory practices. While the SLS cannot combat racism in any sense, it does eliminate some of the discretionary powers of a supervisory officer that are prone to abuse. The SLS may even protect offenders from police corruption by corroborating their version of events. Of course, these goals place stringent demands upon our device: location data must be precise and reliable, and false alarms must not be sounded.

The use of GPS to determine the position of an individual is a relatively straightforward process. GPS now can pinpoint an individual's location to within 3 meters, a considerable improvement over old technology that could only narrow the location to somewhere within the area of a football field.[219] Please refer to appendix 3 for further details and limitations of the technology.

Legal Issues and Privacy Concerns Raised by SLS

The use of electronic monitoring devices on parolees is not a new idea. Electronic anklets have been placed on individuals under house arrest for some time. Even now there are several devices similar to ours in use. For example, Mr. John Zadrayel, a convicted sex offender, carries around a 4-pound box that communicates with a bracelet around his ankle and reports his position via GPS. Mr. Zadrayel is one of 1,200 individuals nation wide who are using these kinds of devices.[220] The SLS and other GPS tracking systems all allow authority figures to monitor peoples' location, a state of affairs which some argue constitutes a potential invasion of privacy.

There are two major cases that set legal precedent on the topic of electronic monitoring and privacy issues: *United States vs. Karo* and *United States vs. Knotts*. Both cases deal with evidence seized through the use of remote tracking of beepers via radio receivers. In *Knotts* government agents placed a beeper in canister of chloroform that was sold to one of the codefendants. Through the use of that beeper, agents managed to follow the can to the defendant's cabin. After several days of visual surveillance, the agents obtained a warrant and discovered that the can was under a barrel outside the cabin and that there was an illegal drug lab inside. The defendant's moved to suppress the lab evidence because it was obtained by monitoring the beeper without a warrant. The United States Supreme Court ruled that this monitoring did not "invade any legitimate expectation of privacy and that there was no search or seizure within the contemplation of the Fourth Amendment." The court reasoned that the use of the beeper to track the car amounted to "following of an automobile on public streets, there being no expectation of privacy in having a car observed arriving on one's premises after leaving a public highway."[221] In *Karo*, circumstances were nearly identical. Government agents placed a

beeper in a can of ether, and then observed one of the codefendants load the can into his car. They tracked him to a house where they determined via the beeper that the can was inside. The can was moved from the defendant's house to several other houses, a storage locker, and finally to a house rented by three other codefendants. Again, agents determined that the can was inside this rented house with the beeper and obtained a warrant to search the property. They were able to seize a large amount of illegal drugs during this search. In this particular case, the Supreme Court ruled that the monitoring of the beeper inside private homes violated the owners Fourth Amendment rights to privacy and invalidated the warrant, suppressing the evidence gained in this manner.[222] It is clear from these two decisions that the measure of the legality of tracking is the reasonable expectation of privacy. Vehicles on open roads do not meet this standard, but the insides of private homes do.

Placing our tracking device on a person is legally analogous to the use of beepers in *Karo* and *Knotts*. When they are outside of their homes, offenders can be considered equivalent to the vehicles in *Karo* and *Knotts*. While moving about in the community, parolees and probationers do not have a reasonable expectation of privacy. Granted, their tracking device will indicate their location more thoroughly than visual surveillance, but they are still traveling in public areas where their actions are visible to all. Therefore, GPS-monitored individuals are not experiencing an invasion of privacy outside their homes. The issue becomes more complicated when an individual is inside a private residence. Using the device to monitor the individual in their own residence would, by the precedent set in the aforementioned court cases, entail an invasion of privacy. However, the SLS circumvents this situation in three ways. First, as mentioned earlier,

the device powers down during periods of negligible movement, such as would be the case inside a home. Secondly, as previously discussed, the precision of GPS, while much improved, is not sensitive enough to gain any information about what an individual does inside a residence. And finally, it is firmly established that parolees and probationers sign away many rights in the terms of their release. These conditions vary by jurisdiction and the severity of the crime committed, but they usually stipulate that the offender, as well as his property, may be searched without a warrant. Thus, precedent allows individuals serving nonincarcerative sentences to legally monitored and searched without a warrant in their own homes or anywhere else. Generally, the SLS raises no new questions of legality. Similar devices are being used to serve the same purposes, and have been for years.

CONCLUSION

In the end, the question of whether wearable monitoring devices should or should not be used may not be as much a moral issue as a legal one. As Edmund L. Pincoffs argues in *The Rationale of Legal Punishment*:

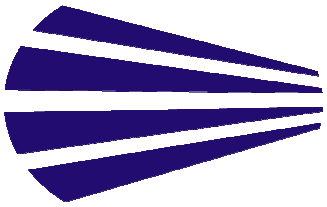
> "What is it for a practice to be just? [T]he assessment of the justice of a practice involves the conception of a particular view of the practice. It is the view taken of it by a person who realizes that a practice is necessary, and that this one will fulfill the need; who also realizes that in any practice there are going to be burdens and privileges; and who must decide whether these privileges and burdens are fairly apportioned in view of what the practice is designed to accomplish.[223]

We have shown that better supervision of nonincarcerated offenders is a great need in the modern United States and that SLS technology protects the safety of the community better and is more sensitive to the rights of the offender than any other currently available

technique; thus it is that we believe that the Sentinel Location System is a just and practical solution to the problems plaguing the United States Criminal Justice System today.

APPENDIX 1

Executive Summary of TRX Systems Business Plan



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EXECUTIVE SUMMARY

Introduction

The business objective of TRX Systems, Inc., is to develop and market intelligent location technology and data management systems for the tracking and recovery of individuals, equipment, and systems. The major competitive advantages of the TRX Systems tracking technology include intelligent path analysis systems, the use of multiple data sources, the size of the device, and other market-specific engineering innovations. Initial focus will be placed on the probationary segment of the US correctional population – nearly 4,600,000 individuals on probation or parole whose movements and behavior are monitored by local government agencies. This approach makes use of Personal Location Technology (PLT) – "wearable" technology used for locating and tracking individuals. As the impact of electronic location technology in the commercial marketplace continues to grow, so does the already enormous potential market for PLT. Initially, TRX Systems will produce applications for high payoff market niches such as government probationer tracking. The choice of probation as an entry market will insulate the company from any market fluctuations due to the stability and structure of government contracts. Also, notwithstanding the recent push to spend additional government money for security, the TRX Systems PLT will save governments significant funds, while providing services not otherwise available from a competitor. Other applications such as monitoring and tracking high value assets, health care monitoring, and the home commercial market are natural spin-offs of the basic PLT.

Market analysis indicates a potential annual market of $1.0 billion or more in revenue from monitoring individuals in the parole/probation segment of the US correctional population. For example, the state of Florida charges each individual on probation an annual fee of $1,200 for supervision services. TRX Systems projects that charging 50% of that fee for its monitoring technology and service per user would save the state significant funds by reducing officer overhead while also reducing probationers' recidivism.

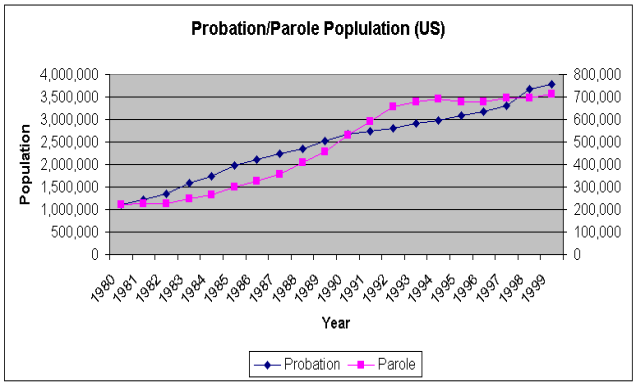


Figure 1 Growth of the US Correctional Probation and parole population 1980 –1999.

Initial products include:

- The *Sentinel Location System* (SLS) – a wearable device capable of recording its location on a fixed medium and playing back locations and track history. A sensor to determine whether an individual is driving a car (to monitor individuals with suspended driving permits) will be used in the first implementation of incorporating multiple data sources in path analysis.[1]
- The *Location Manager System* (LMS) – a PC software suite for retrieving data from the SLS, recording it in a database, producing activity reports, and displaying location histories on maps. The system will provide intelligent data analysis and mining tools for the design and implementation of more effective probation strategies. Compatible platforms include, but are not limited to, Windows 3X, 95, 98, 2000, and XP.

[1] The driving detector technology appears to be novel. A patent application will be prepared in the near future to protect the technology.

Application Markets

TRX Systems has chosen Probation/Parole enforcement as the first market for its SLS. The SLS presents law enforcement communities with a novel tool that will provide a strong, individualized deterrent to the perpetration of further crime.

It is clear that the concept and technology can be adapted to many other applications, which are summarized in subsequent sections. As the technology matures, there will be substantial growth in both the markets and in the technologies available.

Emergency Alerting and Location Systems for Fire, Police, EMS, and Military Personnel

When Fire, EMS, Police, or military personnel enter a dangerous area, the risk of injury or incapacitation poses a serious threat. An obvious need exists for a system that can automatically transmit an alarm and the location of a person who is injured or non-responsive, e.g., in a burning building, or an officer-down alarm for police or military personnel. By adapting the SLS and the PLC to function inside a structure and to detect injury or immobility, TRX Systems will serve this important market niche. TRX Systems anticipates premium pricing for this very specialized, high performance technology.

Location and Tracking of Escaped Prisoners

Manhunts for escaped prisoners frequently prove to be expensive and dangerous endeavors. A device capable of transmitting prisoner location in real time would not only facilitate a more efficient recovery of escapees, but could also act as a deterrent. A modified version of the SLS would be of great value to law enforcement agencies

involved in frequent prison transportation. Discussions with a member of the Montgomery County Sheriff's Office have provided positive confirmation of their need for such a system.

Location and Tracking of Mentally Challenged Patients

Alzheimer's patients, autistic children, and other mentally challenged individuals often have a tendency to wander, leaving family members to face the frightening ordeal of searching for their missing loved one. The TRX Systems SLS, when paired with the PLC, will give families the peace of mind that even if a loved one wanders, he will be quickly and easily found. The technology may be configured to issue an alert and to initiate a homing signal when an individual leaves a pre-specified area.

The Value Proposition

Cost savings, public safety, and prisoner overcrowding are the key elements that will drive the need to purchase our products. With a national prisoner growth rate of more than 5.3%, there is a critical need to place nonviolent offenders on parole. Use of TRX Systems products frees up valuable space inside current prisons. Also, it costs around $13,600 per year to keep a person incarcerated in a minimum-security facility, a cost far higher than being monitored by PLT while on probation or parole.

The TRX Systems SLS design features a compact configuration that is approximately the size of an automatic opener of automobile doors, and contains the following characteristics: location detection accurate to within five meters; long battery

life; low price (the target price is around $180 dollars per SLS unit); robust physical attributes; and expansion versatility.

The unit's two distinguishing physical qualities are its low power consumption, which enables over a week of battery life before recharging, and its physical compactness, which renders it unobtrusive to the wearer.

Competitive Advantage

Engineering innovations.

A current assessment of our competitors' products yields fundamental technical inefficiencies that we aim to overcome. Most importantly, the SLS offers engineering innovations not offered by other companies. The SLS is one compact wearable unit versus a bulkier multi-component system. Because of this, most agencies have avoided GPS-based technology in favor of surveillance and more limited electronic home detention techniques. By not having an additional "power pack" to carry along with the bracelet our system is less conspicuous, making it ideal for everyday activity. Some competitors require their customers to recharge their location systems on a daily basis, whereas the SLS battery will last for over a week. Consequently, the SLS does not place any extra responsibility on the user for the product to operate correctly.

Intelligent path analysis.

Additionally, the LMS uses intelligent path analysis systems to monitor large amounts of tracking data and to make reasonable decisions, without any human facilitation, about the target's behavior.

Multiple data sources.

Coupling this capability with multiple data source management, additional trends can be identified. Multiple data source management offers the ability to intelligently compare location data with, for example, operation of a vehicle, blood alcohol content measured by Breathalyzer, atmospheric conditions, and other information. For example, the driving habits of a probationer with a suspended license can be tracked and the law enforcement user can be alerted.

Tamper-resistant design

The TRX Systems parole and probation devices are designed to be tamper-resistant, so that an offender would have extreme difficulty in removing it in a short period of time. If, for some reason, the device is removed, enforcement officials are notified of the violation.

Stage of Development

Currently, TRX Systems is in the prototype stage of development, and is projected to be in the test-market stage by the second quarter of 2002. With the exception of some minimal seed capital to purchase some initial materials for research and development, there is no revenue. At this point in time there are no paid employees, but there are 17 people actively developing the company, including a successful entrepreneur and University of Maryland professor. TRX Systems is currently in the process of developing its sales and marketing plans, and will begin marketing the product with a small sales team to local law enforcement agencies by the second quarter of 2002.

Target Market Information

TRX Systems intends to earn 10% of the correctional industry share. There are approximately 4,486,000 persons on probation or parole; this leads to around 450,000 units sold, not including the share of current prisoners who will be placed on parole after the system is adopted by an agency. The yearly average rate of increase is 3.7% for probationers, 3.2% for parolees, and 5.8% for prisoners, so the market is growing at a healthy rate.

TRX Systems plans major competition against the following companies: Pro Tech Monitoring, BI Incorporated, and iSecureTrac Corporation. All three of these companies sell GPS-based personal location systems marketed to the parole/probation market segment. BI Incorporated is the largest of these companies and as of the 2nd quarter of 2001, they have over 40,000 individual tracking devices in use. TRX Systems' position in the market is secure because all major competitors offer products that are larger and more unwieldy which place extra responsibility on the offender, while none offer the use of multiple data sources.

Another expected competitor is Applied Digital Solutions (ADS), whose GPS tracking device, Digital Angel, has biomedical features and has the potential to be applied to the parole/probationer market. ADS primarily markets their products to private consumers, but they have recently announced plans for a one-year pilot of a parolee-tracking system.

Several important barriers to entry exist in the personal location industry. Research and development costs are non-trivial, and there are several patents in the area.

Other barriers include the high level of experience in the field among established companies and a concern over privacy issues among citizens and public interest groups. The costs for customers to switch from a non-electronic probation/parole system will mainly be the costs of the system and units. Training will be provided with the purchase of a system, and agencies will realize an immediate operating cost benefit by reducing the need for active officer tracking. The costs for customers to switch from a home perimeter system to the SLS will depend on the extent of their previous investment. Again, costs related to the system are limited to leasing of the equipment; training will be provided. The immense benefits of having a system that can monitor offenders outside of their homes will make the change in investments worthwhile.

Assuming that TRX Systems can obtain the requisite start-up funding necessary to begin production of the SLS and LMS systems, the company anticipates sales to local law enforcement agencies beginning in the third quarter of 2002.

Revenue and Profit Model

TRX Systems will earn revenue by providing law enforcement agencies and other customers with equipment and ongoing service. Financial estimates put the average delivered cost of each SLS unit at $173.80, and the LMS at $3,574.50. Assuming a price of $663.70 for each SLS unit, and $8,000 for the LMS, expected margin over average total cost is $4,425.50 for the LMS and $489.90 for each SLS.

Because of donations and resources provided by the University to student-founded businesses, initial fixed costs per unit are expected to be very low. For example, TRX Systems may apply to the University's TAP program, which will provide below-

market rent office facilities. The Hinman CEOs program will facilitate the offering of *pro bono* legal services and other support. TRX Systems should be profitable within the first year of sales. First year projections of sales are $3,680,000, yielding a profit of $647,468. These projections are based upon a progression towards having a 10% share of the probationer/parole market by the conclusion of 2005.

Funding

Thus far, TRX Systems has received the following monies:

- University of Maryland - $3,000
- Motorola - $1,200

TRX Systems also receives equipment and research facilities from the University of Maryland's Department of Electrical and Computer Engineering.

Intellectual Property

The TRX Systems personal location device has the ability to track and record a person's location and other required data. The device consists of a GPS chip, embedded computer, antenna, internal power supply, and removable flash hard drive. The device also has the ability to interface with a cellular board, allowing it to transfer data over established cellular networks. This feature allows an efficient, quick, and cheap method of sending data in a wide range of areas with very little onsite setup. In addition to transmitting the data, the device stores data in the removable drive allowing for physical transfer of data from the device. We see patentable and other protectable innovation in the following cutting-edge technologies:

- Selected models of the device feature communications algorithms allowing full remote control of diverse services from the device.
- Intelligent computer algorithms permit analysis of location information. Combining GPS results with other real-time data permits computer-based decision algorithms to identify areas of concern in large amounts of data.
- All tracking devices feature rugged casings that are waterproof and weather-resistant. Research and development allows us to formulate unique casings that meet application specifications with respect to shape, weight, material, and other factors.
- The TRX Systems main module includes a real-time embedded operating system with real-time scheduling algorithms to handle GPS data receiving, storing, processing and other actions if pattern matching of the data indicates that further action should be taken.
- Configurable selective polling by the device allows extension of battery life by powering down unused components until the desired function is required.
- The portable device is "hot-pluggable" at a base station computer, allowing data to be transferred from the portable storage module to the personal computer with no additional user intervention.

The client software features the ability to monitor location by accelerated playback on a map, and to cross-reference location data to street names to produce a human-readable report. In displaying location data, interface innovations will make rapid

review of data possible by displaying parallel data points (for example, location, temperature, and speed) on a map using specialized visual encoding.

Team

TRX Systems is staffed by a University of Maryland (UM) professor and by 16 senior UM honors students from diverse backgrounds. The team is also part of the Hinman CEOs Program. Our key personnel are listed below.

- CEO Gilmer Blankenship is Professor and Associate Chairman of Electrical Engineering at the University of Maryland. He is an experienced entrepreneur, having served for the past 13 years as a co-owner and an officer of Techno-Sciences, Inc., the world's leading supplier of satellite aided search and rescue (SARSAT) technology. He is co-founder of Trident, Ltd., a UK company engaged in monitoring and security services for the global maritime industry.
- COO Robert Sherman is pursuing a degree in Human-Computer Interaction. His academic research experience deals with the implications of technology on government and public policy. Professionally, Mr. Sherman works in the government contracts practice at the law firm of Crowell & Moring, LLP, in Washington, DC.
- CFO Adam Sparks is pursuing a double degree in finance and economics. His experience includes a recent internship with Merrill-Lynch where he assisted in financial consultation and the management of securities portfolios.
- CTO Tia Gao is pursuing a degree in computer engineering, with a focus in real-time and embedded systems. She has conducted research at the Software

Engineering for Real-Time Systems Laboratory, and has handled Fortune 500 clients as a software engineering consultant at the Andersen Advanced Technology Department.

- Director of Marketing Jordan Baker is pursuing a degree in marketing. He is the founder and owner of the successful online magazine, PastePunk.com. Mr. Baker has completed two summers of interning at the law firm of Parola, Gross & Marino in New York.
- In addition to these individuals, TRX Systems will be able to access the expertise of Techno-Sciences. TSi has current projects in 9 countries and marketing activities in an additional 7 countries.

APPENDIX 2

Implementation Details of the SLS prototype

Introduction

This project explores the approach of using motion sensors on wearable devices to determine the specific activity of the subject wearing the device. Examples for user activities include driving in a car, sleeping, running, and so on. Determination of a particular situation typically requires substantial analysis and fusion of data from individual sensors.

The final system integrates simple sensors to measure the speed, location, and acceleration motions of the subject. The information is recorded and can later be downloaded and used to determine the situational context of the subject. Work to date has been based on integration of a GPS sensor to measure speed and location, and accelerometers to measure acceleration motion.

Design Decisions

Design Goals

Automatically saved data

The logged data will be saved onto non-volatile memory in the system, so it is not lost if the power source is disrupted. The logged data includes: X-axis Acceleration, Y-axis Acceleration, Latitude, Longitude, Velocity, Time, and Date.

Expandable memory

It is easy to increase the memory capacity of the unit by simply inserting a higher capacity memory card into the system. No additional configuration of the new memory card is needed.

Maximal battery life

Since this is a mobile application, the entire device will be battery powered. The system must be sustained by battery power for at least 24 hours to be a viable and competitive application for parolee tracking.

- **Low power devices.** The sensors and microcontroller used for this project was selected for their low-power consumption and available power-saving modes.
- **Efficient power management.** Efficient power management is essential for extending battery life of the device. To conserve power, the device controller will turn off sensors and enter sleep-mode and when appropriate.
    - This system will sample location/velocity data at a maximum rate of 1 Hz. In between each sample, the idling microcontroller will be put into power-saving mode.

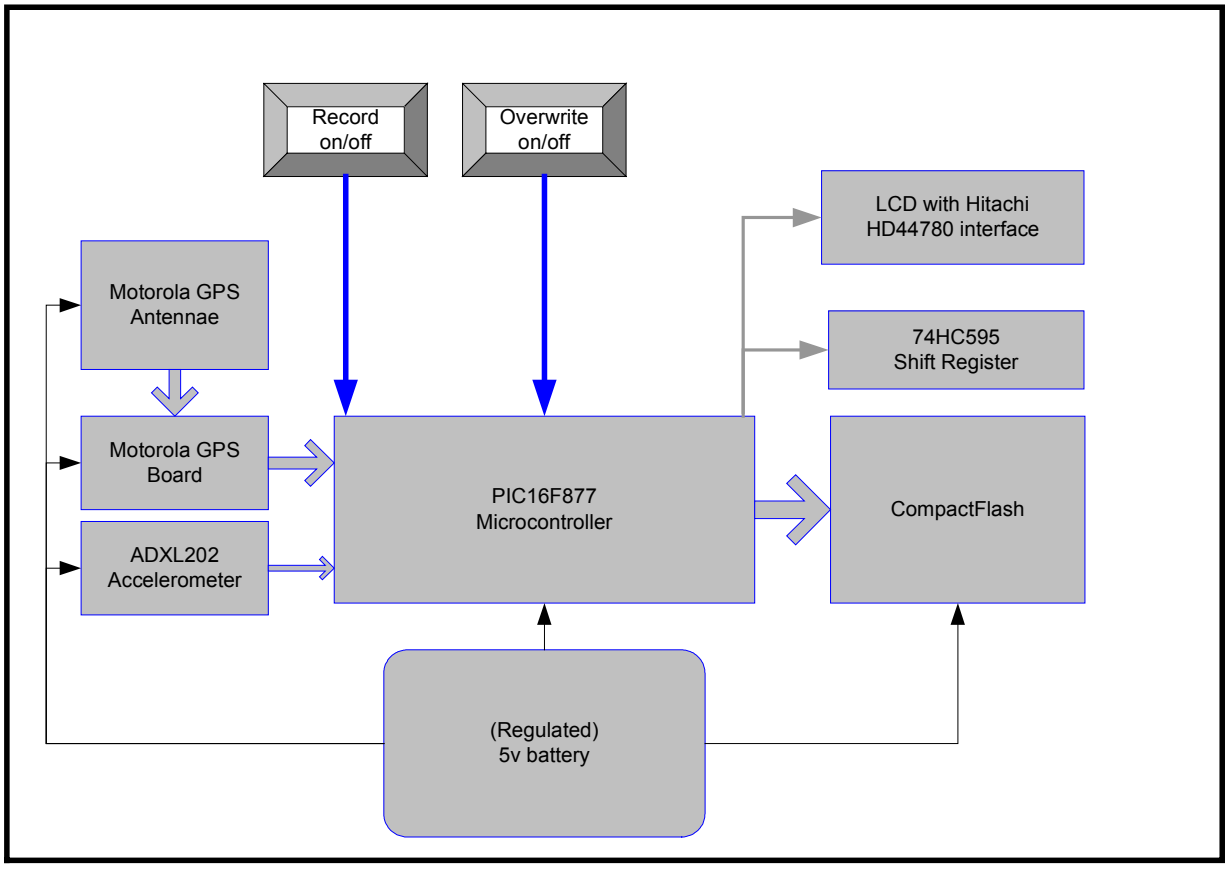
Minimal size

The system must be small enough to be comfortably strapped to a person's wrist and ankle. Size is a signification factor when choosing each system component for this project.

System Components

Figure A2.1 illustrates the major system components. Two toggle buttons: Record and Overwrite, are used to control the system.

The microcontroller receives GPS sentences from the GPS board, and displays the essential data onto the LCD display. To begin recording, the Record button is pressed On and the Overwrite button is pressed Off. The microcontroller then writes the accelerometer and GPS data into the CompactFlash, appending the data to the last position that it has written to. To set the data logger to begin recording at the beginning of the CompactFlash card, Record and Overwrite are both pressed On.



FigureA2.1: Diagram of System Components

GPS receiver

A Motorola Oncore GPS chip and antennae is used for this project. This model is selected for its low power consumption and its idle mode. The current implementation of this system always keeps the GPS receiver in active mode. In the future, the implementation can be improved to save power by lowering the data collection rate, and switching the GPS chip and antennae to idle mode when GPS data does not being collected.

Accelerometer

The objective for selecting the accelerometer was to consume as little power as possible and do not require a unit specific calibration.

Analog Device's line of small piezo-electric MEMS accelerometers is chosen for this project. The particular model used is the ADXL202: a digital output, low cost, low power, complete 2-axis accelerometer with a pre-calibrated measurement range of ±2 g. It is able to measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity).

Microcontroller

The brain of this system is Microchip's microcontroller PIC16F877 (RISC design with 35 instructions). It was chosen for this project for the following desirable features:

- **Flash-programmable memory**. This allows the memory to be quickly overwritten repeatedly during development. Non-flash-programmable

devices requires the program to be burned into the chip and can only be programmed once, thus making the chip unsuitable for development purposes.

- **33 digital configurable I/O pins.** In the future, additional sensors may be added to the system. These I/O pins also offer an abundance of internal peripherals, such as UART serial I/O and A/D converter, to support easy integration with different varieties of sensors.
- **Idle mode.** To conserve power, the microcontroller will switch into idle model after writing to the flash drive.

CompactFlash

The commercially popular CompactFlash was chosen as the recording medium for this project due to its low cost (~$80 / 128 MB) and widespread availability. In addition, it has several other desirable features: non-volatile medium, compact size (one third the size of a PCMCIA memory card), fewer interface signal requirements (50 pin on a CompactFlash instead of 68 pins on a PCMCIA memory card).

Based on the CampactFlash Association specification, there are two modes of access to a CompactFlash: Common Memory mode (requires an 8-bit wide data bus) and True IDE mode (requires 16-bit data bus). Data is written to the CompactFlash in Common Memory mode to take advantage of the lower data bus bit requirement.

The CompactFlash makes it easy to download the data from the system onto a computer. CompactFlash is a subset of PCMCIA cards, making them compatible with any PCMCIA card reader on a PC or laptop. Therefore, when the data need to be downloaded from the device, the CompactFlash is simply removed and plugged into a PCMCIA card slot on a PC or laptop to begin reading its data.

Implementation Details

GPS NMEA-0138 Format

There are about 15 different sentences that the Motorola GPS chip can output. The only sentence used in this project is the required minimum specific GPS/transit data (the GPRMC sentence). All sentences begin with a '$' and end with a carriage return. The figure below illustrates the GPRMC sentence and its contents.

Sample NMEA RMC sentence received from GPS Board:

$GPRMC,225446,A,4916.45,N,12311.12,W,000.5,054.7,191194,020.3,E*68

Sentence terms:

225446

Time of fix 22:54:46 UTC

A

Navigation receiver warning A = OK, V = warning

4916.45,N

Latitude 49 deg. 16.45 min North

12311.12,W

Longitude 123 deg. 11.12 min West

000.5

Speed over ground, Knots

054.7

Course Made Good, True

191194

Date of fix 19 November 1994

020.3,E

Magnetic variation 20.3 deg East

*68

mandatory checksum

Figure 2 Sample NMEA RMC Sentence

CompactFlash Configuration

The CD1 signal of the CompactFlash is grounded internally and connected to the microcontroller. The microcontroller will detect the presence of the CompactFlash if the

pin is low. The control signals used are: CE1 (data bus enable), active low OE (output enable), and WE (write enable).

All data on the CompactFlash can be accessed via three address lines. To write to a register on the CompactFlash, one byte data is placed on the 8-bit data bus to the card, the 3-bit address of the destination register is placed on the address lines to the card, and the WE pin is strobed low. This writes the first byte into the CompactFlash buffer. To writ the next byte, a new byte is written to the data bus, the address bus remains unchanged, and the WE signal is strobed low again. Only after the entire buffer has been written, the data is transferred to the card memory from the buffer.

Almost all commercial CompactFlash cards on the market have sector and buffer sizes of 512 bytes. Thus, a full 512 bytes must be written to the buffer before it is written to the card memory.

Microcontroller Configuration

FigureA2.2 illustrates the connections to the 40-pin PIC16F877. A blank row indicates the pin is not used in this project. There are 6 unused pins, which are all tied to ground with 10kohm resistors to prevent interference with the rest of the circuit.

Pin	**FUNCTION**	IN/OUT
1	MCLR: pull up with 10kohm R to begin executing program code	In
2	RA0: connect to X-axis output of the accelerometer	In
3	RA1: connect to Y-axis output of the accelerometer	In
4	RA2: connect to toggle button	In
5	RA3: connect to toggle button	In
6		

7		
8	RE0: controls the address line (A0) of the CompactFlash	Out
9	RE1: controls the address line (A1) of the CompactFlash	Out
10	RE2: controls the address line (A2) of the CompactFlash	Out
11	Vdd: 5v	
12	Vss: gnd	
13	CLKIN:	In
14	CLKOUT:	Out
15	RC0: flash	
16	RC1: signal low indicate CompactFlash card is present	In
17	RC2: flash	
18	RC3: flash	
19	RD0: connect to D0 of CompactFlash's 8 bit data bus	Both
20	RD1: connect to D1 of CompactFlash's 8 bit data bus	Both
21	RD2: connect to D2 of CompactFlash's 8 bit data bus	Both
22	RD3: connect to D3 of CompactFlash's 8 bit data bus	
23	RC4: to WE on CompactFlash (active low)	
24	RC5: signal high indicate CompactFlash is ready for read/write	In
25	RC6/Tx: internal **Tx** USART Asynch Transmit connected to GPS	Out
26	RC6/Rx: internal **Rx** USART Asynch Transmit connected to GPS	In
27	RD4: connect to D4 of CompactFlash's 8 bit data bus	Both
28	RD5: connect to D5 of CompactFlash's 8 bit data bus	Both
29	RD6: connect to D6 of CompactFlash's 8 bit data bus	Both
30	RD7: connect to D7 of CompactFlash's 8 bit data bus	Both
31	Vss2: gnd	In
32	Vdd2: 5v	In
33		
34	RB1: connect to LCD_Latch on 74HC575's 3 pin input bus	Out
35	RB2: connect to LCD_Clk on 74HC575's 3 pin input bus	Out

36	RB3: To ICD	X
37		
38	RB5: connect to LCD_Data on 74HC575's 3 pin input bus	Out
39	RB6: To ICD	X
40	RB7: To ICD	X

Figure A2.2: PIC16F877 I/O Connections

Interface between microcontroller and power/clock/controls:

(9 pin interface) 2 power lines, 2 ground lines, 2 clock lines from 4MHz resonator, 2 control lines from toggle buttons, 1 jumper line.

Interface between microcontroller and GPS Receiver:

(2 pin interface) 1 data line (Rx: receive), 1 control line (Tx: not implemented, but desirable for future features)

The internal UART in the microcontroller is used to receive the data from the GPS. The microcontroller runs at 4MHz with a GPS data rate of 2400 baud.
The microcontroller obtains the NMEA-0183 GRMC sentence from the GPS receiver, decodes by the microcontroller and displayed on the LCD character display. The content of the received data is specified in Figure 2.

Interface between microcontroller and LCD:

(3 pin interface) 3 control lines to shift register & LCD display.

The microcontroller operates the character display in the 3-bit mode in order to save on data lines does this.

Interface between microcontroller and accelerometer:

2 data lines: port RA0 will receive X-axis data from accelerometer and RA1 will receive Y-axis data from the accelerometer.

Interface between microcontroller and CompactFlash:

(17 total pins) 8 data lines (Port D), 3 address lines (Port E), 6 control lines (Port C)

Everything from position, heading, and speed to temperature and wind direction can be encoded into an APRS data packet. In order to save power and memory space, only the minimal information necessary to track the mobile system is recorded.

The packet format is shown below.

Sample sentence written to CompactFlash:
/225446/A/4916.45,N/12311.12,W/000.5/
Sentence terms:
225446
Time of fix 22:54:46 UTC

A
Navigation receiver warning A = OK, V = warning

4916.45,N
Latitude 49 deg. 16.45 min North

12311.12,W
Longitude 123 deg. 11.12 min West

000.5
Speed over ground, Knots

Figure A2.3: Sample string written to CompactFlash

Hardware Schematic

Figure 4 shows the circuit diagram of the most complex interface in this project: the 17 pin microcontroller to CompactFlash interface.

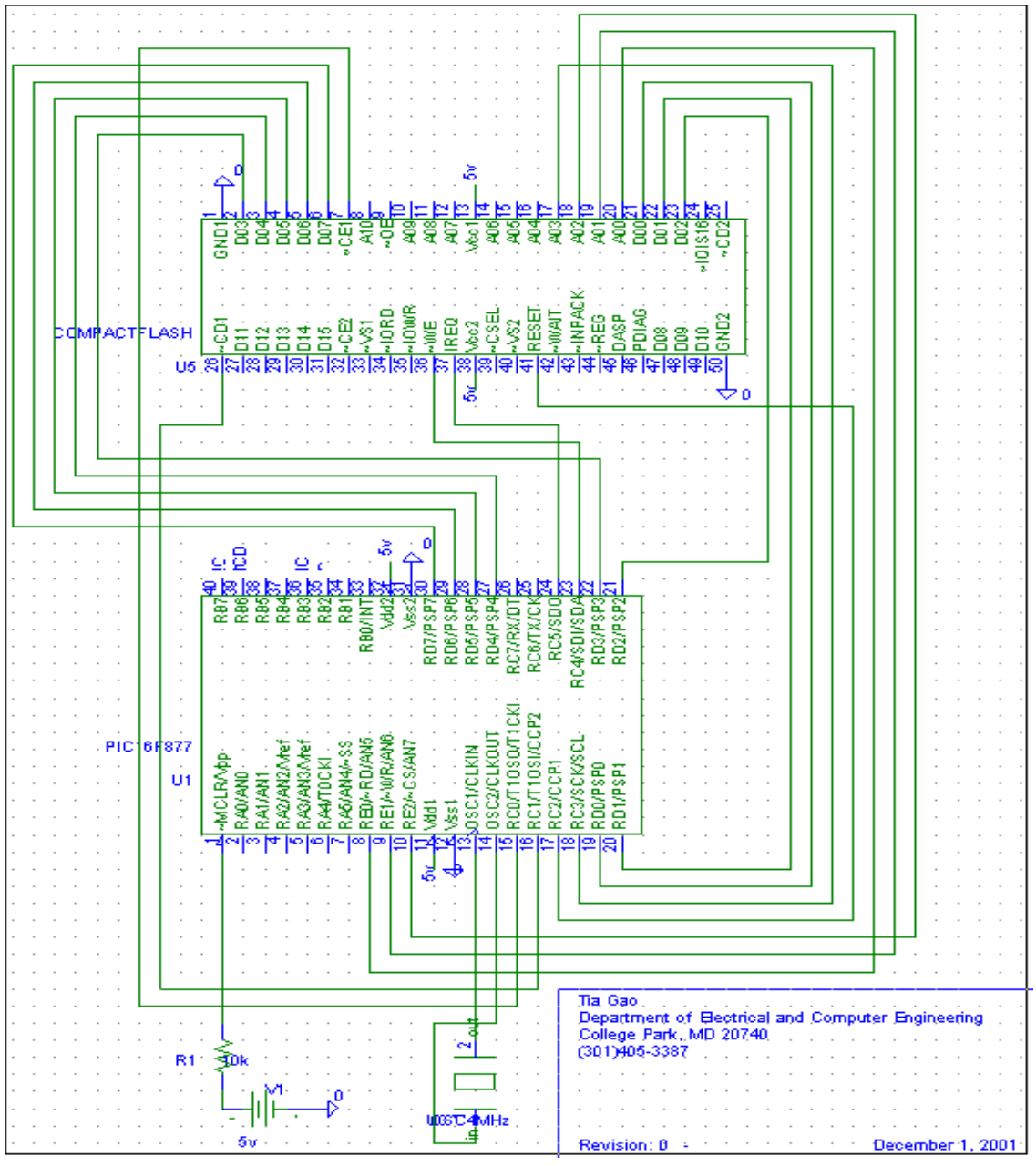


Figure A2.4: Microcontroller interfaces to power and CompactFlash

Software

The PIC processor programs are written in C.

On boot, the PIC processor reads the (Record: On/Off) input on port RA.2. If Record is set to On, the processor reads the (Overwite:On/Off) input on port RA.3. If Overwrite is On, the next CompactFlash memory address is initialized to 0x0000 and this is saved to the PIC's EEPROM.

If Record is On and Overwrite is Off, the PIC periodically receives data from the GPS board, fetches the address of the next CompactFlash location from the PIC EEPROM, writes the GPS data to this address in the CompactFlash, increments the address pointer and saves to the PIC EEPROM. That is, the memory address pointer is implemented using nonvolatile memory. Thus, if power is lost, any data, which has been logged, is not overwritten. Rather, logging picks up where it left off.

The logged data is displayed on a serial LCD for development purposes, in order to monitor the data that is written to the CompactFlash.

In order to save power, the processor goes into sleep mode if it receives invalid GPS data for ten minute. The processor sleeps for an additional ten minutes, and is waken by its watchdog timer wakes up to begin sampling data again.

Development Equipment

The following tools were used during the development of this project.

Microcontroller Simulator

The MPLAB Simulator is used to simulate programs before they are written to the microcontroller.

Microcontroller Debugger

MPLAB-ICD module is an in-circuit hardware debugger is used to write the program into the microcontroller and execute the code.

C to Assembly Compiler

Majority of the code is written in C, with the rest written in PIC16F877 assembly. The C is compiled into the PIC16F877 assembly code with the CCSC PSC compiler.

Problems Encountered

Microcontroller I/O limitation

The PIC16F877 has only 1 USART serial I/O port. The interface to the accelerometer and the GPS can both easily be implement with USARTs. However, since only 1 USART was available, the GPS used the microcontroller USART, and the accelerometer used other non-USART pins.

Equipment bug

The oscillator that successfully drives other PIC models could not drive the PIC16F877 microcontroller. Without realizing that the problem was in the oscillator, significant amounts of time were spent on tracing the problem. So even though the code was written and simulated with the MPLAB simulator and then written to the PIC16F877 on a real circuit board, the microcontroller could not execute its code without a working oscillator to drive its program counter.

Conclusion

This prototype established the feasibility of creating a low-power motion and location data logger by designing the system with both software and hardware considerations: by choosing particular power-efficient hardware components and writing software to minimize power loss. Potential applications of this system ranges from medical applications to law enforcement. The next step in this research project is employ signal analysis algorithms to perform motion pattern recognition on the recorded data.

Future Research

Advanced Power Management

- More power management functionality can be implemented to improve the battery life of the system. If the individual wearing the device is detected to be

inactive (velocity and acceleration below a set threshold) the entire unit should enter sleep mode until the individual moves in a significant manner.

Additional Sensors

- Visual sensors that capture photographic images can be a powerful addition to the system. Very specific and clear determination of the individual's environment and activity can be derived from visual context. Resource and power constraints on the device typically do not permit the capturing and processing of images from visual sensors for this past semester's project.

- Gyroscopes used to measure angular velocity. Since skeletal components are all connected by hinged joints, their relative motions are primarily rotational. Thus, gyroscopes that measure angular position can provide critical information to determine the motions of the individual. Since gyroscopes were less commonly used in engineering applications than accelerometers, their prices were significantly higher than the accelerometers. The cheapest gyroscope, similar in size and precision to a $2 accelerometer, costs $50[224]. For this reason, gyroscopes were not used during this past semester's project.

Other Works Referenced

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4. Microchip, PIC16F87X microcontroller datasheet, http://www.microchip.com/1010/pline/picmicro/families/16f87x/

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6. Circuit Cellar Online, “PIC a Flash Card,” February 2001, http://www.circuitcellar.com/online

7. Motorola, 8-bit Serial Shift Register with Latch datasheet: http://www.programmationworld.com/site/langages/progelectronique/downloads/cours8/74hc595.pdf

8. PIClist website, PIC FAQ, http://www.piclist.com

APPENDIX 3:

Global Positioning Systems Function, Capabilities and Limitations

Global Positioning Satellite, or GPS, technology is widely used to provide worldwide location capabilities. The technology was originally used by the United States military to coordinate military actions, such as the precision aiming of the Tomahawk cruise missile. In fact, until May of 2000, the system was considered too accurate for non-military use. The United States military intentionally introduced error into the signal so that those without government-provided decoders would have accurate information only to within 100 meters.[225]

The system works using a network of 24 geosynchronous space satellites that transmit a formulaic message. These satellites are arranged in six orbital planes, with each containing four satellites each. These 24 satellites are managed by the military at designated Control facilities, the main facility being at Schriever Air Force Base in Colorado. The military constantly monitors the satellite network and uploads the necessary data to the GPS satellites as needed. GPS receivers, which are either stand-alone end-user products or components of more complicated technology, then receive a message from these satellites.

Using a process called triangulation, a GPS receiver can compute its current location, velocity, and time. At least four satellites are required for what is considered to be an "accurate" three-dimensional fix. However, many receivers can theoretically communicate with up to twelve satellites at a time, providing an even more accurate location to the user. Usually between five and eight satellites are visible from one location on the Earth's surface at any time. Using 12 satellites, the Motorola Oncore GPS receiver used in the SLS device can triangulate its location to within 5 meters RMS.[226] However, because the GPS receiver must have a line-of-sight to the satellites,

the signal can be lost. Generally, once at least four satellites are acquired, the process of triangulation involves the device receiving standardized time information from each individual satellite.

By comparing the time sent from the first sending satellite to the actual time, it is possible to know how long the signal took to reach the receiver. This information is used to determine how far the receiver is from the satellite. Since the satellite knows its exact position orbiting the earth based on its regular orbit plan and the previously mentioned corrections from the United States Department of Defense, the receiver knows that it is somewhere on the surface of a sphere with the computed radius from the known satellite position.

The second satellite uses the same process, generating a sphere on which the receiver must be. Comparing the overlap between the first and second spheres, a much smaller region can be determined. Adding a third satellite narrows the region down to just two points in space; the fourth resolves the absolute location. After physical location is determined by the GPS receiver in a standard format (the Sentinel Location System device uses a format called NMEA 0183), that information is used by other components of the device. In a simple end-user GPS unit, this use may be as simple as displaying the latitude and longitude of the receiver or plotting change in location on a chart.

The TRX-Systems technology is more complex - it takes the output from the GPS component and processes it in two steps. First, the data are parsed within the location device to isolate only the information of interest such as location and the timestamp. Other supplementary information, such as input from accelerometers, is also accepted.

This data are stored on a removable flash memory card or transmitted to a remote location using wireless communication technology.

The second phase of data management in this system is done remotely, on a personal computer with the Location Manager System (LMS). The software retrieves the location and supplementary data either in real-time via a wireless link or after the fact from flash memory and conducts operations on it such as rendering and displaying it for a user. The LMS software is also responsible for matching physical addresses to location and time data, and comparing those addresses and times to a database of locations of interest, such as locations where police dispatch records indicate criminal incidents or locations where judicial orders prohibit an offender from frequenting.

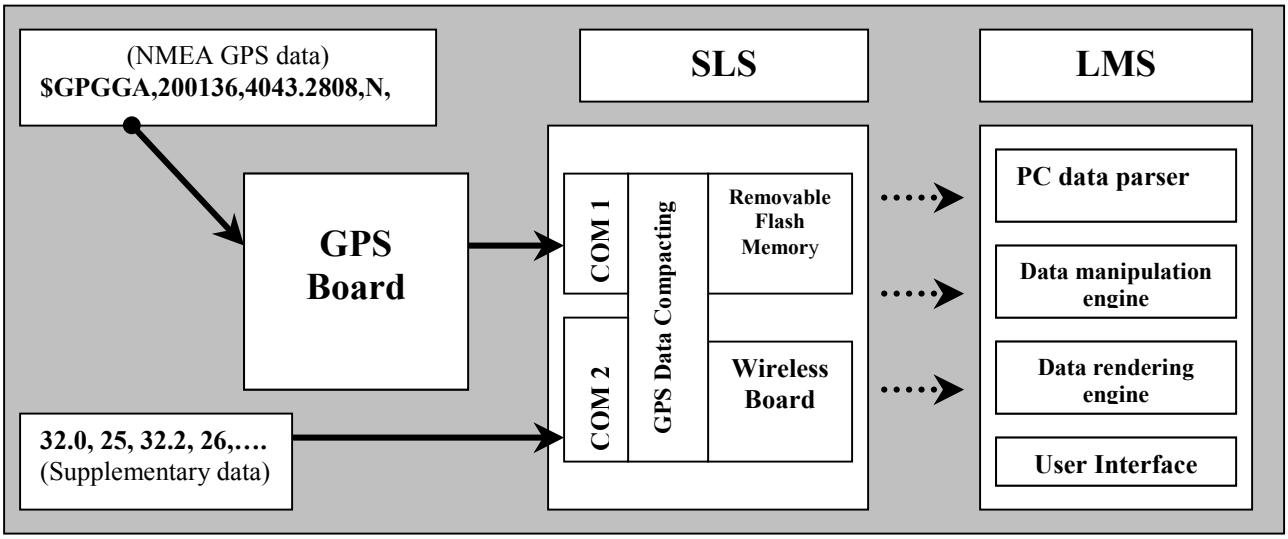

Figure A3.1: Global Positioning Satellite data path in Sentinel Location and Location Manager Systems

APPENDIX 4:

Sentinel Location System Wristband Unit Materials Design

Introduction

In modern engineering many techniques are available to help the assist engineers in the product design process. In the early seventies, Quality Functional Deployment (QFD) was introduced and became a valuable tool. Today, engineers have access to a huge number of resources such as the House of Quality, the Pugh Matrix, the 'Design for X', and the Design for Manufacturing and Assembly (DFMA). The DFMA is employed by many companies around the globe and has proven to be one of the more successful techniques. This appendix will familiarize the reader with the DFMA process as it relates to selecting appropriate materials and methods to create the wristband for the Sentinel Location System.

Our analysis has determined that magnesium is the best material to use in the fabrication the wristband. Materials were judged on the criteria of strength, durability, reliability, expense, weight, and aesthetics. When compared with other sufficiently strong materials, such as steel, titanium or carbon fiber, magnesium is relatively light and very inexpensive. Careful material choice results in lightweight units with a lower consumer cost and an increased profit margin for TRX Systems. The appearance of the final product is also important. Aesthetics significantly contribute to brand recognition and customer acceptance.

Since the product will be a mass-produced item, the wristband will be a cast part. Choosing the wrong form of casting can result in high costs, defective casts, and difficulty in manufacturing. Because the selection of casting technique so is essential to producing a quality part, this appendix will also review different types of casting, the science behind casting, and the design considerations for casting. We will focus on the

process of magnesium pressure casting in particular, to determine if and to what extent such a method simplifies or complicates the manufacturing process. But before a DFMA analysis of casting is possible, Design for Manufacture and Assembly must be defined.

Design for Manufacturing and Assembly

DFMA provides a systematic procedure for analyzing proposed designs from the point of view of assembly and manufacture.[227] DFMA is comprised of two strategies employed in early stages of the design process: Design for Manufacturing (DFM) and Design for Assembly (DFA). DFA designs a product for simplified assembly, taking into consideration number of parts, orientation, and cost. DFM is similar but considers the constraints of manufacturing. Most design groups follow a process similar to the outline shown in Figure A4.1.[228]

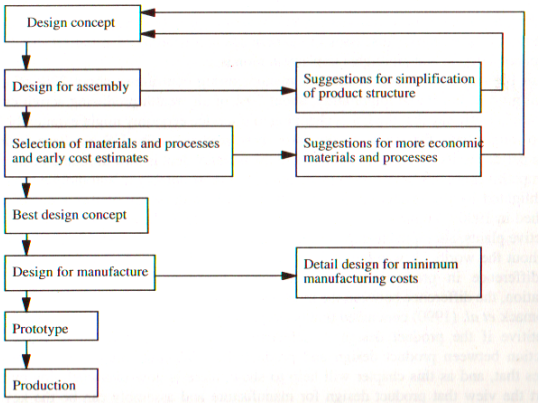

Figure 4A.1: Engineering process flow chart

Together, DFA and DFM form a solid basis for creating cost-effective, easily assembled, and easily manufactured products. Note that DFMA presents cyclical process that keeps returning to the concept phase. This is very different from the linear "over the wall" approach illustrated by Figure A4.2.

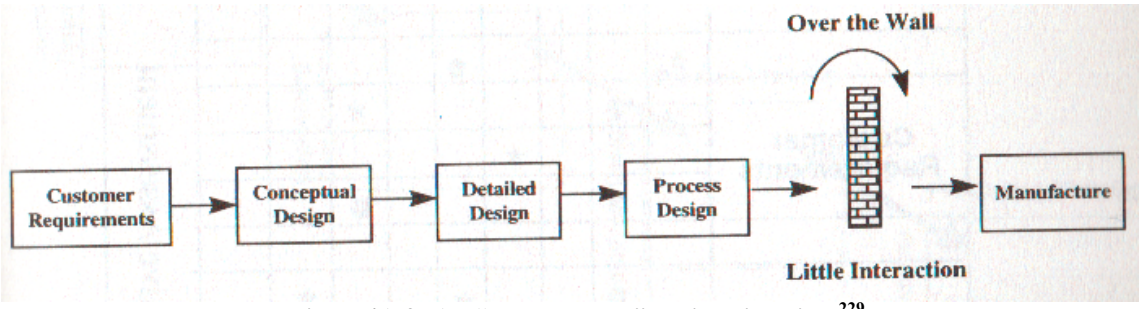

Figure4A.2: An "over the wall" design situation.[229]

Over the wall approaches typified design engineering in the past.[230] Though DFMA may require more effort on the part of the engineers and may result in a longer lag between concept and prototype phases, but the result pays for itself in by reducing overall costs and problems. Many major companies have begun to employ DFMA to streamline their production. In 1991, GE Automotive formed a special design team focused on generating long-term results by implementing design for manufacturing and assembly. Their goals were to cut costs, improve efficiency, add capacity, create new business, and produce better quality.[231] The results were astounding: Figure A4.1 displays data from the 1992-1993 season.

	Number of Parts			Assembly Costs		
Part	**Original**	**After DFMA**	**% Decline**	**Original**	**After DFMA**	**% Decline**
Head lamp	67	42	32%	$11.81	$6.96	41%
Sturctural instrument	178	107	40%	$13.51	$9.46	30%
Front door	327	307	6%	$38.44	$27.21	29%
Accelorator petal	13	2	85%	$1.28	$0.09	93%

Figure A4.3: GE Automotive's results after just one year of DFMA use. [232]

This is just one example of many successes GE Automotive has experienced with the application of design for manufacture and assembly. Overall, DFMA saves the company approximately $500,000 per project every year.[233]

History of Casting

Casting has been an integral part of technological advances throughout history. In Mesopotamia around 5000 BC, copper was first cast in open molds to produce axes and long blades.[234] The Bronze Age was born roughly a thousand years later when it was discovered that alloying copper with tin produced a more castable metal. Development in casting techniques continued to improve as new metals were discovered, technology improved, and societies changed. Casting was used to create of one of the seven wonders of the ancient world, The Colossus of Rhodes; it was one of the few sciences to survive the Dark Ages; and it sustained all aspects of the America war effort in World War I. Casting advances produced iron, the blast furnace, cast type and the printing press, and the Industrial Revolution: each of these milestones dramatically and permanently altered human society. To this day, metal casting remains an integral part of art, technology, and war.

Science of Casting

What is casting?

Casting is a manufacturing process in which a mold is filled with molten material that upon solidification takes the shape of the mold.[235] While the process of superheating a metal, alloy, or polymer, pouring this 'melt' into a mold or die, allowing

the melt to cool and removing the cast from the mold seems relatively simple, the processes necessary to carry out these simple steps over a large range of materials are very complex.[236] Whole treatises have been devoted to the subject.

The primary distinction between various methods is the type of mold used during the manufacturing process. Choosing the correct mold is an important choice. The choice depends on properties of the casting material and dramatically impacts the shape, size, surface finish, and finally the cost of the final product.[237]

For the remainder of this appendix, we shall focus on metal castings since a magnesium cast part has been proposed for the wristband. While there are many variations on casting techniques, the following section will focus on those most pertinent to the SLS.

Types of Casting

The four most popular types of casting are: sand casting, plaster casting, investment or lost wax casting, and various forms of pressure die casting.

Sand Casting

Sand casting involves a part that is cast from a sand mold. The first step in the process is creating a pattern for the part. Patterns are formed from foam, wood, clay, or plastic models. The model must be a near match to the actual component with allowances for shrinkage and finishing. The model is placed in the bottom of the sand mold, the "drag". Placing the model in the drag and packing sand tightly around it forms a relief in the shape of the molded part. The top of the mold, called the cope, is then positioned and tightly packed with sand. Sand is mixed with clay or polymers to allow

better packing around the pattern. Simple casting can be made in one piece, provided that the piece can be removed from the sand without disturbing the pattern. Complex patterns are created with two or more sections to facilitate component removal from the sand without harm.[238] After the pattern is set, the cope and the drag are separated to remove the model from the mold. This hole, called a cavity, will be filled with the molten component material. Once the cavity is created, a poring channel, or "feed", is cut into the sand to allow the molten material to enter the cavity. Extra voids in the mold are strategically placed to allow air pockets to escape from the cavity and ultimately allow the creation of a solid part. The two halves are rejoined and molten metal is poured into the cast until it emerges from feed. The cast solidifies by sitting at room temperature or by being dipping it into a cold-water bath. After cooling, the flask is broken apart and the part is removed. The sand can then be reclaimed for future use in another mold.[239]

A second type of sand casting is called shell molding. In this process, a metal pattern is heated to 175 – 350 degrees Celsius, coated with a lubricating agent such as silicone, placed in a box, and sprinkled with a mixture of fine sand and phenol formaldehyde - a thermosetting resin binder.[240] Just before the resin is allowed to set, the pattern is removed from the shell mold and heated in an oven to fully set the mold. Again a channel is created and the molten material is poured into the cavity. Castings fabricated with this method tend to result in more accurate dimensions and fewer surface defects compared to the conventional sand casting method.[241]

Plaster Casting

Plaster casting begins with creating a model from wood, plastic or metal. The model is then placed into a container called a flask and covered with a lubricating compound. Typically, the cope and the drag are created separately, which confers the advantage of reusable molds. A plaster compound is then poured into the flask covering the mold. After the mold has set, the model is removed and the mold cured by baking. This process leaves small, interconnected pores in the plaster, but these holes are useful because they vent gases built up during the casting process. The two halves of the mold are then fit together and a molten metal is poured as in sand casting. When the metal has cooled, the mold is separated and the parts are retrieved.[242]

Investment or Lost Wax Casting

Investment casting, also called lost wax casting, begins with the creation of a model done in an expendable material such as wax or plastic. The material is then covered with a ceramic or plaster material and baked. During the baking process, the wax melts and drains or vaporizes out of the mold, leaving a relief. When the pattern has cooled, a melt can be poured into the mold. Once the metal has cooled, it is quite difficult to remove from the mold. Chemicals, sand blasting, and pressurized water jets are the standard methods for freeing the past.[243]

Die Casting

One popular permanent mold casting technique is called die-casting. Die-casting is a method of creating castings of nonferrous metals where molten metal is forced into a

special mold, called the die, under pressure. The die composition depends largely on the material to be cast, because the die must have a higher melting point than cast material. Parts made from iron or steel typically come from graphite dies made from graphite, which has a much higher melting temperature than steel. Parts made from aluminum or magnesium alloys, however, can be cast in steel dies.[244] Though zinc alloys are most commonly used in die casting, aluminum, brass, magnesium and other nonferrous alloys are also used. The major advantage die casting has sand casting is the rapid and economical generation of castings with automatic machines.[245] Additionally, die casting allows for the casting many components simultaneously, and provide a finer finish and more detail.

This process injects molten metal under high pressure into precision steel dies machined from high quality tool steel. The dies are heat-treated to exact specifications and held together with between 400 and 1200 tons of pressure while the injection of molten nonferrous materials takes place. After filling, the dies are applied with even more pressure as the metal solidifies. Finally, the machine applies a light coat of releasing agent to the die and ejects the casting. This process is illustrated in Figure 4A.4.

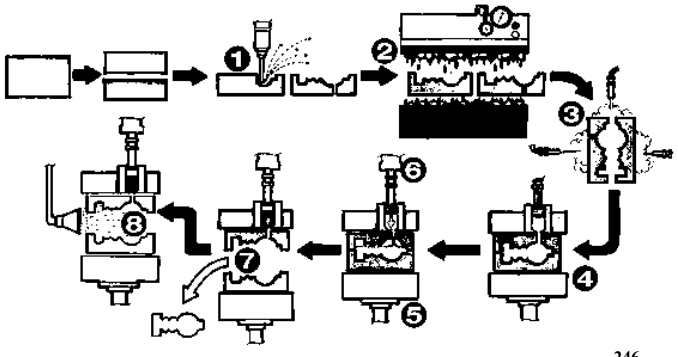

Figure 4A.4: Illustration of the die casting process.[246]

Through the years, die-casting methods have evolved into an art more than a science. To date, there exists five types of die-casting methods including: hot chamber high pressure die-casting, cold chamber high pressure die-casting, gravity or permanent mold die casting, low pressure die-casting and squeeze casting.[247] These processes variously enhance fine detail, part integrity, and surface quality.

Design for casting

Selecting a Casting Process

In order to successfully cast a part, several items must be considered. First, the function specified by design engineering must be maintained. These specifications encompass tensile strength, density, and longevity in the environment in which the part is to operate. Second, the functional shape of the part must be maintained. Design considerations at this level include the ease of manufacture and aesthetics.[248] These two sets of demands must be weighed against one another to determine the most suitable way to manufacture the part in question. Once the method of manufacture is determined, further considerations based on the manufacturing method must be evaluated. In the case of the wristband on the SLS, it has been determined that the best way to create that part is through metal casting, to which we now turn our attention .

Metal casting of the wristband requires that the casting process is able to accurately deliver the shape and function of the band. We require a part that is free of internal and external defects, such as cracks or tears, and that meets the dimensional requirements of the design.

The factors that must be considered when selecting a casting process are the material from which the part is made, the number to be made, the part's shape and size, its dimensional tolerances, and the cost of manufacturing. First, the number of parts to be created will eliminate some forms of metal casting. For instance, the wristband of the SLS is a mass produced part. It would not be economical to create this part using plaster or lost wax casting since at high production volume metal die-casting is much cheaper.[249] Secondly, the dimensional tolerances of the part are relatively low. A typical tolerance in sand casting is 1/16".[250] This is much too large for the wristband since it is attached to the SLS at many locations, and must provide clearance for each band to be interlocked together and move freely as once piece. This leaves gravity die-casting or pressure die-casting. Both can provide tight tolerances and are economical for mass production. How does one decide on which process to select? The answer comes from the type of material that is being cast.

Material Considerations

Material comparison

The three materials considered for SLS wristband construction were magnesium, aluminum, and zinc. These choices share a suite of structural and economical properties that plastics, copper, ceramics, and steel do not. Major criteria for candidate materials include: fatigue strength, weight, rigidity, impact resistance, and aesthetic appeal. The properties of elemental magnesium, zinc and aluminum are listed in FigureA4.5 below.

Property	Magnesium	Zinc	Aluminum
Weight	24.30g/mol	65.39g/mol	26.98 g/mol
Density	1738kg/m^3	7140 kg/m^3	2700 kg/m^3
Hardness	2.5	2.5	2.75
Rigidity	17 Gpa	43 Gpa	26 Gpa
Melting Point	923 K	692K	933K

Figure A4.5: Properties of elemental materials suggested for use in the SLS. Source: The Online Materials Information Resource[251]

The weight-saving advantage of magnesium over aluminum is well known. The alloy we have selected, AM60 magnesium, is approximately 33% lighter than aluminum and over 60% lighter than zinc.[252] Magnesium has comparable mineral hardness to both aluminum and zinc, though it is the least rigid.[253] All three metals require a surface pretreatment before painting to ensure adhesion.[254] These pretreatments are usually chemical and also provide additional corrosion protection. Magnesium alloys are as resistant to saltwater corrosion as any aluminum or zinc alloy. Most importantly, die casting of magnesium has two distinct advantages: extended die cast tooling life and faster die casting machine production rate.

Short die life, slow production rates, heat checking of the cavity steel, and porosity are four problems which have plagued the die cast industry for years. Heat checking is an effect of heat fatigue on the cavity steel due to repetitive heating and cooling of the cavity. This stress warps the die and decreases the tolerance of finished parts in mass production. It is not uncommon to see signs of washout and heat checking after as few as 10,000 shots on a die running aluminum. Rapidly deteriorating steel in the cavity requires die or cavity replacement after 150,000 to 200,000 shots.[255] Because magnesium does not have the affinity for tool steel that aluminum has, it will not attack the cavity steel like aluminum does. Die casters running magnesium report tool life four to five times greater than that normally experienced with aluminum. There are many

magnesium production tools still in daily operation that have more than 500,000 shots on them.[256] Many of these tools produce thin-wall castings, much like the SLS wristband, that require a high-quality surface appearance.

Thanks to magnesium's rapid solidification and anti-soldering characteristics, faster die casting rates are achieved than with aluminum. Dwell times (amount of time in the die) and spray cycle times (amount of time to cool the die after one shot) are significantly shorter for magnesium. A 25% to 50% improvement in machine cycle time is attainable in die casting magnesium, as compared to aluminum.[257]

Cost Factors

Some important cost data that should be considered when choosing die casting material can be illustrated using a hypothetical case given by a company that manufacturers many cast parts for large companies around the world.[258] (All case-related figures are from the Magnesium Aluminum Corporation) Figure A:4.6 shows the casting wall used in our example:

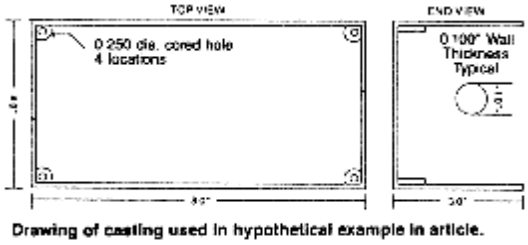

Figure A4.6: Hypothetical cast part.

Consider rectangularity shaped casting measuring 8 x 4 x 3 inches high with a wall thickness of 0.1 inch. On the inside of this box, there is a ¼ inch diameter cored hole in a ¼ inch diameter boss in each corner. At each end of the part there is a 1-in. diameter

through-hole that is centered in the end of the part. Figure A4.7 presents data in analysis of the casting:

Table 1. Parameters used in analyzing casting used as example.

1. Product life is five years	
2. Volume is 200,000 parts per year	
3. A two-cavity die casting die with two core pulls on each cavity is required	
4. Cost of material:	Aluminum-$0.85/lb. Magnesium;$1.43/lb. Zinc-$0.90/lb.
5. Die cost is $45,000	
6. Estimated die life:	Aluminum—167,000 shots Magnesium—500,000 shots Zinc—500,000 shots
7. Size die casting machine: 500-ton cold chamber	
8. Estimated hourly rate for 500 ton machine: $70/hr.	
9. Part weight:	Aluminum—1.07 lb. Magnesium—0.72 lb. Zinc—2.26 lb.
10. Casting rate in pieces/hr:	Aluminum—200 Magnesium—300 Zinc—450 (hot chamber)

Figure A4.7: Parameters used to analyze the casting example.

In this case, the end user of the casting would benefit considerably by selecting magnesium. They would not only achieve a 33% reduction in weight, but would also achieve favorable pricing considerations due to the increased die casting cycle rate and today's favorable price ratio on magnesium to aluminum of 1.68:1.[259]

Tooling Costs

Tool costs are calculated on the production volume over the life of the product. In this case, it was estimated that the tool would have to be replaced two times during the life of the product if it were run in aluminum. The same tool running magnesium or zinc would last for the life of the production runs. In calculating the aluminum tool replacement costs, a 10% increase in the cost of the tool each time it was replaced was anticipated. Figure A4.8 presents a breakdown showing how the tooling costs were calculated:

Table 3. Calculating the amortized tooling costs used in example.

Cost Factor	Aluminum Part	Magnesium Part	Zinc Part
Original cost of 2-cavity die casting die	$45,000	$45,000	$45,000
Replacement cost at 167,000 shots	49,000	—0—	—0—
10% add-on for capital investment	4900	—0—	—0—
Replacement cost at 324,000 shots	54,450	—0—	—0—
10% add-on for capital investment	5445	—0—	—0—
Total die casting tool costs for life of production runs	159,345	45,000	45,000
Die casting tool cost per part (amortized over 1 million parts)	$0.159/pc	$0.045/pc	$0.045/pc

Figure A4.8: Breakdown of tooling costs.

As shown by this example, the cost of a part will vary considerably based on material content and tooling replacement costs. Although raw magnesium is more expensive than raw zinc or raw aluminum, its excellent manufacturability makes it less expensive after production. FigureA4.9 presents a cost breakdown for each material.[260]

	Aluminum	Magnesium	Zinc
Metal	$0.91/per cast	$1.03/pc	$2.034/pc
Casting	$0.35/pc	$0.233/pc	$0.156/pc
Tool	$0.159/pc	$0.045/pc	$0.045/pc
TOTAL:	$1.419/pc	$1.308/pc	$2.235/pc

Figure A4.9: Cost breakdown for materials.

In summary, magnesium is easily castable and able to hold tighter tolerances than aluminum, which may eliminate additional machining steps and reduce costs. Magnesium's superior machinability allows the use of high speeds and heavy loaded feeds, which result in fewer machines, less capital investment, less floor space, and less labor overhead requirements than aluminum. Finally, the use of die casting with magnesium alloys is backed by several decades of continuous use and testing. In many

cases, thirty-year data are available.[261] This documentation enables the accurate prediction of warranty costs and may sharply reduce product liability.

Reasons for Choosing Pressure Die-Casting

Once magnesium was selected as the metal for economical and availability reasons, the type of casting was be selected. The options have thus far been narrowed down from five to two, they are gravity die-casting and pressure die-casting. It turns out that magnesium is very volatile at high temperatures and oxidizes easily when exposed to air.[262] Oxidation of the cast part significantly degrades its mechanical properties and opens the possibility of internal defects in subsequent parts. Gravity die-casting involves pouring molten metal out of the melting crucible and into the die, presenting the strong probability of oxidation. Significant resources would have to be spent removing the oxidation from the surface of the cast part and off-gassing the molten metal to remove the oxygen. For this reason pressure die-casting would appear to be the best manufacturing process to use.

Material and the casting method used are not the only decisions that must be made before production begins. The die design considerations must also be addressed.

Die Design

Die design is an intricate process. The first aspect that must be considered is the orientation of the cast part in the die. This is a crucial consideration since it is possible to cast a part that cannot be removed from the die without destroying the part or the die. In

addition, the orientation must be such that it minimizes the die volume and thereby production costs. For example, consider the cylinder (a) to be cast in Figure A4.10.

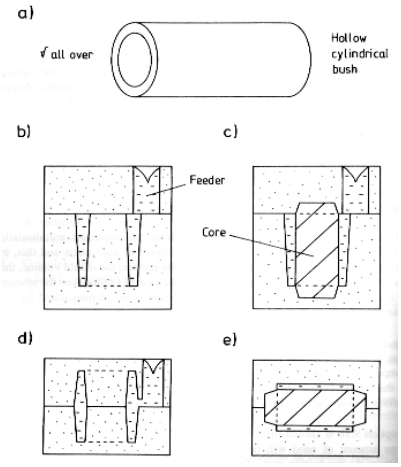

Figure A4.10: Possible die orientation.[263]

Orientations (b) through (e) show possible casting options. Each option would be able to create the cast part, but some orientations are superior. Dies (d) and (e) are better than dies (b) and (c) because the volume of the die is smaller meaning the cost of the die will be less as well. Die (e) is a better selection than die (d) because even though casting the cylinder horizontally requires a core, the need for a taper or draft on the part is eliminated, lowering finishing costs by eliminating machining.[264]

In addition to orienting the cast part to most efficiently utilize the volume of the die, the cast part must be oriented to ensure the melt will reach all parts of the mold before solidification creates blockages. A blockage occurs when the melt freezes in a narrow section of the die and prohibits more molten metal from flowing past it and into incompletely filled areas. The best way to avoid this is to arrange the cast part so that the largest volumes to be filled are closest to the feed and the smallest volumes farthest from the feed. The feed is where the molten metal is forced into the mold. Figure A4.11 shows two possible orientations of a cone shaped part.

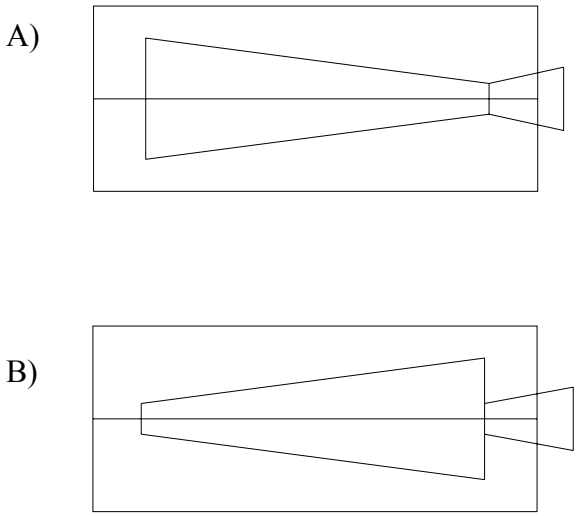

Figure A4.11: Cone shaped part.

Orientation B is clearly the better choice for casting since it allows the feed to enter through the larger end of the cast. This allows the molten metal to reach the farthest ends of the cast before freezing.

After the melt has been poured and the cast part has been allowed to cool, the part must be removed from the mold. It is important that cast parts have been created in such a way as to facilitate this. By using a technique know as drafting, parts may be created to easily separate from their dies based on geometry. By slightly tapering all vertical angles in the die so that the area of parting line is the largest, a draft is created. The advantages of this are twofold. First, the melt will travel from large to small regions of the die facilitating the previous requirement. Second, this will allow the cooled part to be removed from the die easier (Figure A4.12). As the cast cools, it shrinks. In the case of a draft, this shrinkage acts to pull the cast away from the walls of die and out of the mold. Not utilizing a draft can cause serious difficulties when trying to remove a cast object from its die, especially if the geometry of the shape is complex.

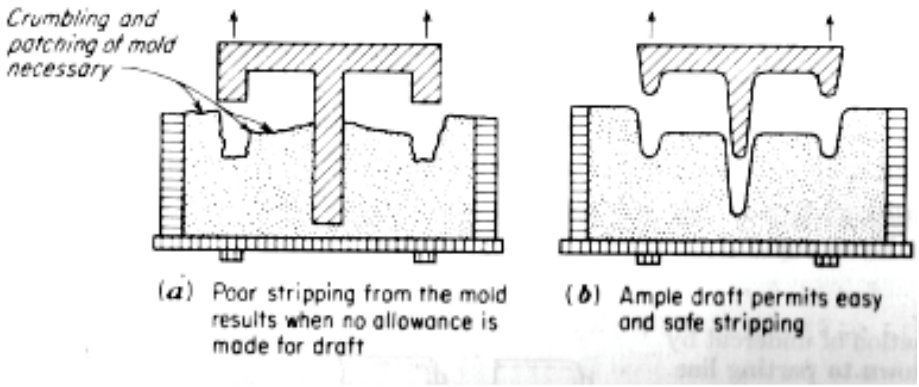

Figure A4.12: Illustration of drafting technique.[265]

A complete understanding of the concepts outlined in this appendix facilitates the application of intelligent assembly and manufacturing design. The use of DFMA techniques has helped TRX Systems select appropriate part materials and manufacturing processes to minimize product defects and maximize production uptime and tool lifespan in our efforts to product efficient, high-performance products at low cost.

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